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RADIATION AND NUCLEAR SAFETY AUTHORITY

IRPA

XVIII NSFS Conference

"Next Level in Radiation Protection"

Proceedings

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NORDIC SOCIETY FOR RADIATION PROTECTION

Proceedings of the NSFS XVIII Conference

NSFS 2019

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Dear colleagues

It was a great pleasure to welcome more than 130 participants from around the world to the XVIII conference of the Nordic Society for Radiation Protection – held in Espoo 10-14 June 2019.

The theme for the conference was “Next level in radiation protection”. It was concluded that learning from the past is a key issue in the development of new recommendations. Research cooperation platforms were considered important arenas for development of scientific basis for radiation and nuclear safety and the need for both Nordic and European projects as well as national projects was recognized.

Many high-quality papers were received, making it a pleasure for the programme committee to put together a very interesting program with 56 oral presentations and 29 posters and two panel discussions. Moreover, the first Bo Lindell’s book “Pandora’s Box” out of four books about the history of radiation protection was published in English.

The 2019 receiver of the Bo Lindell award was Mette Øhlenschlæger, who gave a presentation on “Making a difference”. In addition, invited speakers set a scene for next level in radiation protection radiation protection issues: the beginnings of a comprehensive review of the system of radiological protection, overviews of the Nordic co-operation, European radiation protection research activities and nuclear safety knowhow, and current international activities in the field of radiation protection dosimetry and calibrations.

The organizing committee would like to thank all oral and poster presenters, and other participants for taking active part in the discussions. We hope that you in addition to all the professional activities found time to relax and mingle among colleagues and to enjoy Hanaholmen Cultural Centre located at the Baltic Sea in the middle of the Finnish nature.

Ritva Bly

President of NSFS 2015–2019

The opinions and conclusions presented in the articles of the proceedings are those of the authors and do not necessarily represent the official position of the Nordic Society for Radiation Protection.

CONTENTS

SCIENTIFIC PROGRAM

Session 1: Opening and Bo Lindell Award

Chair: Ritva Bly, Finland Co-chair: Tommi Toivonen, Finland

S1-O1 **Bo Lindell Lecture:**
Making a difference NOT AVAILABLE
Mette Øhlenschlæger, Danish Health Authority

S1-O2 **The fabulous history of radiation protection – Can we learn from the past?**
NOT AVAILABLE
Jack Valentin, Jack Valentin Radiological Protection
Acknowledging the English translations of Bo Lindell's books on radiation, radioactivity and radiation protection.

Session 2: Next level in radiation protection: Setting the scene

Chair: Mette Øhlenschlæger,Denmark Co-chair: Ole Harbitz, Norway

S2-O1 **The beginnings of a comprehensive review of the system of radiological protection** NOT AVAILABLE
Christopher Clement, ICRP

S2-O2 **A boost to radiation protection by the Nordic co-operation** NOT AVAILABLE
Sigurður Magnússon, [1]NKS, [2]Icelandic Radiation Safety Authority

S2-O3 **Overview of European radiation protection research activities** NOT AVAILABLE
Teemu Siiskonen, Radiation and Nuclear Safety Authority (STUK)

S2-O4 **Nuclear safety knowhow as a national strategy**
Marja-Leena Järvinen, Radiation and Nuclear Safety Authority (STUK)

S2-O5 **Current international activities in the field of radiation protection dosimetry and calibrations** NOT AVAILABLE
Paula Toroi, IAEA

Session 3: Actions for justification

Chair: Jukka Liukkonen, Finland Co-chair: Eija Venelampi, Finland

S3-O1 **Health technology assessment - Could RP influence the choice of medical technologies and methods.**
Eva G. Friberg, Norwegian Radiation and Nuclear Safety Authority

S3-O2 **Nordic participation in European Action Week -Inspections of justification in radiology**
Eva G. Friberg, Norwegian Radiation and Nuclear Safety Authority

S3-O3 **A road-map for developing referral guidelines for diagnostic imaging in the Russian Federation**
Aleksandr Vodovatov, St-Petersburg Research Institute of Radiation Hygiene

Posters: Actions for justification

S3-P1 **Perception of the radiation risk among the Russian specialists in radiation protection**
M. Biblin, St-Petersburg Research Institute of Radiation Hygiene

Session 4: New methods and technologies

Chair: Hanne Waltenburg, Denmark Co-chair: Kerttuli Helariutta, Finland

S4-O1 **An on-line system for calculating staff doses - the PODIUM project**
Anja Almén, Swedish Radiation Safety Authority

S4-O2 **NaCl pellets as prospective dosemeters for hospital applications: preliminary experience from Skåne University Hospital**
Lovisa Waldner, Lund University, Sweden

S4-O3 **Spectra Recording Semiconductor Detectors for Medical Imaging**
Joonas Tikkanen, Radiation and Nuclear Safety Authority (STUK)

S4-O4 **Ionizing radiation detection with mobile phones**
Panu Pousi and Jan Morelius, Radiation and Nuclear Safety Authority (STUK)

Posters: New methods and technologies

S4-P1 **Evaluating or reducing the conservativeness of dose estimations**
Quang Le Nghi Trong, Danish Decommissioning

Session 5: Medical applications 1: Focus on high dose procedures and safety deviations

Chair: Alexandra Karoussou-Schreiner, Luxembourg Co-chair: Heli Larjava, Finland

S5-O1 **INVITED: Radiation protection of patient in cardiology**
Joanna Sierpowska, Siun Sote, Finland

S5-O2 **Radiation protection of staff in cardiology and interventional radiology**
Timo Mäkelä, Oulu University Hospital, Finland

S5-O3 **Patient dose variations in cardiology: KAP values and skin doses**
Jukka Järvinen, Turku University Hospital, Finland

S5-O4 **Reporting on radiation safety deviations of medical x-ray practices in Finland**
Elina Hallinen, Radiation and Nuclear Safety Authority (STUK)

Session 6: Medical applications 2: Collaboration, guidelines and deep-learning to improve optimization

Chair: Eva G. Friberg, Norway Co-chair: Raija Seuri, Finland

S6-O1 **INVITED: Effective collaboration between authorities and CT Manufacturers on CT dose optimization**
Alexandra Karoussou- Schreiner, [1]on behalf of Heads of European Radiological Competent Authorities (HERCA), [2]Radiation Protection Department, Ministry of Health, Luxembourg

S6-O2 **INVITED: From image quality to care outcome**
Mika Kortesniemi, Helsinki University Hospital

S6-O3 **Nordic guidelines for dose reduction of radiosensitive organs of patients in conventional radiography and fluoroscopy**
Anders Widmark, [1]Norwegian Radiation and Nuclear Safety Authority, [2]Norwegian University of Science and Technology

S6-O4 **Harmonization of radiation protection, imaging and dosimetry practices of I-131 therapy in Finland**
Tommi Noponen, Turku University Hospital, Finland

Posters: Medical applications

S6-P1 **40-years of Nordic cooperators**
Torsten Cederlund, Swedish Radiation Safety Authority

S6-P2 **Pediatric CT examinations in Iceland: Frequency and age distribution**
Edda Lina Gunnarsdóttir, Icelandic Radiation Safety Authority

S6-P3 **Assessment of dose-area product of common radiographic examinations in selected southern Nigerian hospitals**
Bamidele Lateef, Osun State College of Technology, Nigeria

S6-P4 **On conceptus doses in cardiology in Finland - A simulation Rrport on a CRT implantation**
Jukka Järvinen, Turku University Hospital, Finland

S6-P5 **Whole body counting for staff monitoring in radionuclide therapy with Th-227**
Søren Holm, Rigshospitalet 3982, Denmark

S6-P6 **New Danish guideline for quality control of diagnostic monitors**
Hanne N Waltenburg, Danish Health Authority

S6-P7 **HERCA activities relating to medical applications**
Alexandra Karoussou-Schreiner, [1]on behalf of Heads of European Radiological Competent Authorities (HERCA), [2]Ministry of Health, Luxembourg

Session 7: Radiation and nuclear safety research

Chair: Anja Almén, Sweden Co-chair: Marja-Leena Järvinen, Finland

S7-O1 **Cores-Consortium for radiation safety research**
Pia Vesterbacka, Radiation and Nuclear Safety Authority (STUK)

S7-O2 **Recent Nordic research collaboration results obtained under the NKS-B program**
Kasper G. Andersson, NKS,
Technical University of Denmark

S7-O3 **Radiation protection research: is Nordic cooperation a way forward to ensure sustainable competence and high-quality research?**
Christopher Rääf, Lund University, Sweden

Posters: Radiation and nuclear safety research

S7-P1 **Neutron dosimetry in Nordic countries**
Jussi Huikari, Radiation and Nuclear Safety Authority (STUK)

S7-P2 **Actinium in urine**
Cato C. Szacinski Wendel, Institute for Energy Technology (IFE), Norway

Session 8: Nuclear waste management strategies

Chair: Kasper G. Andersson, Denmark Co-chair: Antero Kuusi, Finland

S8-O1 **INVITED: The role of safety culture and holistic ALARA / ALARP in the optimisation of radioactive waste management in a new nuclear build**
NOT AVAILABLE
Peter Bryant, The Society for Radiological Protection (SRP-UK)

S8-O2 **Introducing the concept of the isodose for optimization of decontamination activities based on typical Northern European houses**
Yvonne Hinrichsen, [1]Technical University of Denmark, [2]Lund University, Sweden

S8-O3 **Upper estimates for effective doses from release of ^{36}Cl activity during plasma cutting of the DR3 reactor tank**
Jens Søgaard-Hansen, Danish Decommissioning

S8-O4 **Difficult to measure beta emitters (^{55}Fe and ^{63}Ni) in activated pressure vessel steel - theoretical versus experimental analysis**
Susanna Salminen-Paatero, University of Helsinki

S8-O5 **Radiation protection of the decommissioning Hot Cells**
Quang Le Nghi Trong, Danish Decommissioning

S8-O6 **Simple contamination, Comprehensive solution - A case study**
Mikkel Øberg, Danish Decommissioning

Session 9: Modern radioecology

Chair: Christopher Rääf, Sweden Co-chair: Tuomas Peltonen, Finland

S9-O1 **A new MiniPANDA detector for measurement of environmental samples**
Timo Hildén, Radiation and Nuclear Safety Authority (STUK)

S9-O2 **Radon concentration in water in Iceland**
Gísli Jónsson, The Icelandic Radiation Safety Authority

S9-O3 **Assessment of the radiation environment around the European Spallation Source before its start**
Christian Bernhardsson, Lund University, Sweden

S9-O4 **A radionuclide model for the main basins of the Baltic Sea - Identification of representative biota**
Ville Kangasniemi, EnviroCase, Ltd

S9-O5 **Feasibility of a HMO-process in drinking water treatment technology for removing natural radioactivity and avoiding generation of NORM**
Siiri Suursoo, University of Tartu, Estonia

Posters: Modern radioecology

S9-P1 **Radioecological sample collection in Finland**
Jussi Paatero, Finnish Meteorological Institute

S9-P2 **Nuclear contamination sources in surface air of Finnish Lapland in 1965-2011 studied by means of ^{137}Cs, ^{90}Sr, total beta activity, ^{238,239,240,241}Pu, and ^{241}Am**
Susanna Salminen-Paatero, University of Helsinki

S9-P3 **Radioactivity on peatlands: ecosystem approach on late-phase fallout situations**
Ari Ikonen, EnviroCase, Ltd

S9-P4 **Airborne lead-210 and stable lead in Subarctic Finland 1964-2013**
Jussi Paatero, Finnish Meteorological Institute

S9-P5 **Aiming for accreditation in gammaspectrometry**
Asser Nyander Poulsen, Danish Health Authority

S9-P6 **Tritium in the Lund area prior to start of the European Spallation Source (ESS)**
Kristina Eriksson Stenström, Lund University, Sweden

S9-P7 **Radon measurements in Þríhnúkagígur cave in Iceland**
Marjan Ilkov, Icelandic Radiation Safety Authority

S9-P8 **Variation in uptake of Cs and Sr by 11 cultivars of oil crops**
Stefan Bengtsson, Stockholm University

Session 10: New methods in emergency preparedness

Chair: Pia Vesterbacka, Finland Co-chair: Veli Riihiluoma, Finland

S10-O1 **Novel gamma radiation detector for Finnish early warning network**
Sakari Ihantola, [1]Radiation and Nuclear Safety Authority (STUK), [2]Helsinki Institute of Physics

S10-O2 **Design principles of enhanced dose rate monitoring network**
Tuomas Peltonen, Radiation and Nuclear Safety Authority (STUK)

S10-O3 **Who Is emergency worker? The Finnish answer**
Antero Kuusi; Radiation and Nuclear Safety Authority (STUK)

S10-O4 **Voluntary Radiation Measurement Team**
Jukka Sovijärvi, Finnish Radiation and Nuclear Safety Authority (STUK)

Posters: New methods in emergency preparedness

S10-P1 **Analysis on different hypothetical radioactive release scenarios on Finnish NPPs**
Antti Ukkonen, Radiation and Nuclear Safety Authority (STUK)

Session 11: Non-ionizing radiation

Chair: Riikka Pastila,Finland Co-chair: Pasi Orreveteläinen, Finland

S11-O1 **Genomic instability and non-ionizing radiation**
Jonne Naarala, University of Eastern Finland

S11-O2 **The health effects derived from UV radiation and sunbed use** NOT AVAILABLE
Riikka Pastila, Radiation and Nuclear Safety Authority (STUK)

S11-O3 **Use of non-ionizing radiation in beauty care**
Pasi Orreveteläinen, Radiation and Nuclear Safety Authority (STUK)

S11-O4 **Sunbed use in Iceland 2004 – 2018**
Edda Lina Gunnarsdóttir, Icelandic Radiation Safety Authority

Session 12: Policies, actions and research to support radiation and nuclear safety

Chair: Jens Søgaard-Hansen, Denmark Co-chair: Maaret Lehtinen, Finland

S12-O1 **Improved radiation safety in Finland with graded approach in the new regulatory framework**
Tommi Toivonen, Radiation and Nuclear Safety Authority (STUK)

S12-O2 **Radon action plan of Finland**
Päivi Kurttio, Radiation and Nuclear Safety Authority (STUK)

S12-O3 **Implementing 3S in practice – Conducting the 3S inspections**
Marko Hämäläinen, Radiation and Nuclear Safety Authority (STUK)

S12-O4 **National best practices: Implementing guide for security arrangements of radiation sources**
Tuomas Siru, Radiation and Nuclear Safety Authority (STUK)

S12-O5 **Methods and challenges of communication in radiation protection** NOT AVAILABLE
Johanna Vahtola, Radiation and Nuclear Safety Authority (STUK)

S12-O6 **Radon at work places - concentrations during working hours vs. long term average**
Olli Holmgren, Radiation and Nuclear Safety Authority (STUK)

Session 12: Policies, actions and research to support radiation and nuclear safety, cont'd

Chair: Søren Holm, Denmark Co-Chair: Hannu Järvinen, Finland

S12-O7 **Nordic project to establish diagnostic reference levels for pediatric patients**
Hanne N. Waltenburg, Danish Health Authority

S12-O8 **Collecting relative frequencies and assessing radiation doses of pediatric radiology procedures involving ionizing radiation: Data collection methods and first results**
Andreas Jahnen, Luxembourg Institute of Science and Technology (LIST)

S12-O9 **Comparison of measured eye lens doses at the forehead and at collar level**
Henrik Roed, Danish Health Authority

S12-O10 **Lowered dose limit to the lens of the eye- Results from 2018 at Forsmark NPP**
Ann-Sofie Gustafsson, Forsmarks Kraftgrupp AB

S12-O11 **INVITED: Global Cooperation in Radiation Protection - case Saudi Arabia**
Pekka Ottavainen, STUK International Ltd.

Posters: Policies, actions and research to support regulatory control

S12-P1 **Diagnostic reference levels (DRL) in Norway 2017: Results, revision and establishment of new DRL**
Anders Widmark, [1] Norwegian Radiation and Nuclear Safety Authority, [2] The Norwegian University of Science and Technology

S12-P2 **Development of national diagnostic references levels for CT in Denmark**
Hanne N Waltenburg, Danish Health Authority

S12-P3 **Assesment of DRLs for PET/CT examinations in the Russian federation**
Larisa Chipiga, St-Petersburg Research Institute of Radiation Hygiene

S12-P4 **Staff eye lens dose in interventional radiology and cardiology**
Antti Pekkarinen, [1]Radiation and Nuclear Safety Authority (STUK), [2]University of Helsinki

S12-P5 **Inspection remarks on transportation of nuclear medicine sources**
Jukka Liukkonen, Radiation and Nuclear Safety Authority (STUK)

S12-P6 **Radon communication in Finland**
Katja Kojo, Radiation and Nuclear Safety Authority (STUK)

S12-P7 **FINNORM - Establishing the NORM inventory of Finland**
Mila Pelkonen, Radiation and Nuclear Safety Authority (STUK)

S12-P8 **Radiation safety in aviation in Finland**
Anne Kiuru, Radiation and Nuclear Safety Authority (STUK)

S12-P9 **General overview on Nuclear and Radiological Regulatory Commission (NRRC) in Saudi Arabia**
Ahmed Basfar, Nuclear and Radiological Regulatory Commission, Saudi Arabia

S2-O4

Nuclear safety knowhow as a national strategy

Marja-Leena Järvinen
Radiation and Nuclear Safety Authority (STUK), Helsinki, Finland

When nuclear technology was being implemented in Finland in the 1960s and 1970s, the significance of research in creating and developing know-how regarding nuclear safety was already clear. Finland's capability of making decisions — independent of the suppliers of nuclear power plants and safety assessments — has been developed systematically. The organization of nuclear energy research has reflected the changes in the operating environment of the use of nuclear energy.

The national nuclear safety and nuclear waste management research programs play an important role in the competence building in Finland. The research has been carried out in from of national programs since the beginning of the 1990s. The final seminar of the latest four year national nuclear power plant safety research program SAFIR2018 was held in March 2019. At the time of the seminar The Ministry of Economics Affairs and Employment (MEAE) published the survey of competence needs of the use of nuclear energy assessed in 2010 and in 2017. The future needs were estimated up to 2030. According to the survey Finland has human resources for the current nuclear energy program.

The program SAFIR2018 is the largest national research program and a significant factor in the field. The results created have been useful for the development of the entire sector and for the regulatory oversight of nuclear facilities. In depth competences are developed in the research projects, in the application of the results achieved, and in various national and international cooperation forums associated with these. The SAFIR2018 research program has received international recognition both in the international evaluation of the program and in connection with the handling of the Convention on Nuclear Safety.

Extensive investments have been made on the nuclear safety research infrastructure in Finland and abroad. The renewal of the nuclear safety research infrastructure has been carried out in program SAFIR2018 and valuable assets have been developed to enable high-level nuclear safety research in Finland. In kind participation to an international Jules Horowitz Research Reactor (JHR) Project in France has created valuable knowhow on the development of an in core test equipment and gamma/X-ray measurement systems.

The planning of the new nuclear safety research programs considered the changes in the operating environment reflecting the changes in the energy system in Finland and global framework. It was guided by the research strategy for the nuclear power sector, covering the period up to 2030, prepared under the supervision of the MEAE. The current four year nuclear safety research program SAFIR2022 and nuclear waste management program KYT2022 started at the beginning of 2019.

S3-O1

Health technology assessment- Could RP influence the choice of medical technologies and methods?

Eva G. Friberg and Ingrid E. Heikkilä
Norwegian Radiation and Nuclear Safety Authority

Medical exposure is an essential tool in diagnosis and treatment of different conditions and diseases. However, ionizing radiation is associated with cancer induction and also acute tissue reactions for some high-dose procedures. To ensure safe introduction of new health technologies, it is important to properly address and evaluate the radiation detriment associated with medical exposure. This is the rationale behind the requirement for generic justification of medical exposure, which has been reinforced in the new European Radiation Protection Directive (2013/59/EURATOM). Norway established in 2013 a national coordinated system for health technology assessment (HTA), bringing all relevant stakeholders together. HTA has been recognized as a valuable tool in promoting generic justification of medical exposure and the concept of generic justification were therefore implemented in this system in 2014. The advantage of this approach is that radiation protection and the concept of generic justification is part of the total assessment and decision-making processes and not evaluated in a separate and isolated system. In this way, radiation protection may influence the choice of medical technologies and methods that are introduced or phased-out in a country. The Nordic radiation protection authorities have published a Nordic position statement on justification of new types of practices involving medical exposure. Integration of generic justification into established methods for assessments of new health technologies is recommended as one approach to strengthen the justification process. A Nordic cooperation has been initiated both between the radiation protection authorities and between the Nordic HTA bodies.

S3-O2

Nordic participation in European Action Week – Inspections of justification in radiology

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Abstract

Justification is one of the fundamental principles in radiation protection and has to be carried out in advance for every individual medical exposure according to the European Radiation Protection Directive (2013/59/EURATOM). However, there are strong indications that up to 20-30% of medical imaging exposures could be unjustified and/or inappropriate in many economically developed countries. Justification is not one single action, but a process that includes a number of steps and different health professionals and staff. It is recognized that regulatory bodies have an important role in promoting and ensuring that the process of justification is properly implemented and carried out at medical imaging facilities. The Heads of the European Radiological Protection Competent Authorities (HERCA) organized a European Action Week on inspection of justification in radiology in November 2016. The aim was to assess whether the different steps in the justification process take place in medical imaging facilities and to identify weaknesses in the justification process across Member States. In total, 17 countries participated in the Action Week and 148 inspections were carried out. The Nordic countries were highly represented and accounted for 37% of all the inspections performed. All inspections were performed according to a common inspection template. The inspections revealed several weaknesses when it comes to proper implementation of justification and there is still an urgent need to increase the awareness and to reiterate the importance of the justification process. The presentation will present the outcome of the Action Week with focus on the results from the Nordic countries.

Introduction

Justification is one of the fundamental principles in radiation protection [1] and its necessity is reinforced in the new European Basic Safety Standards Directive (2013/59/EURATOM) [2]. To ensure the appropriate use of medical imaging, justification has to be carried out at an individual level before the exposure takes place. However, there are strong indications that up to 20-30% of medical imaging exposures are unjustified and/or inappropriate in many economically developed countries [3]. Heads of the European Radiological protection Competent Authorities (HERCA) has recognized that the regulatory bodies have an important role in promoting and ensuring that the principle of justification is properly implemented at medical imaging facilities. Consequently, HERCA has published a position paper on justification of individual medical exposures to provide clarity on the regulatory framework for justification [4]. It is highlighted that justification is not just one action, but a process that includes a number of steps. An effective way to reduce doses from medical exposure is to avoid unjustified examinations. HERCA has identified an urgent need to improve the implementation of justification and therefore organized a European Action Week on inspection of justification in radiology in November 2016.

Purpose

The purpose of this coordinated European Action Week was to assess whether the different steps in the justification process take place in medical imaging facilities, to identify weaknesses in the justification process and to increase the awareness on the necessity of justification in medical exposure.

Methods

All HERCA countries were invited to take part in this Action Week and to perform coordinated inspections in a representative number and type of imaging facilities. All inspections were notified in advance and performed according to a common inspection template. Requested documentation was submitted to the competent authorities prior to the inspections. Results were mainly obtained by interviews and document reviews, aimed to identify if and how justification was implemented in daily workflow. Availability of written procedures for the justification process, assignment of tasks and responsibilities, assessment of justification and appropriateness of referrals, handling of incomplete or unjustified referrals, availability and use of referral guidelines together with performance of clinical audits were among the investigated topics. The overall quality of 10 referrals (5 for CT and 5 for conventional X-ray) per inspected facility was also reviewed to check if there was sufficient information for the radiological practitioner to assess if the referred examination was justified and appropriate.

Results and discussion

In total, 17 countries participated in the Action Week and 148 inspections were carried out across Europe. The Nordic countries were highly represented and accounted for 37% of all the performed inspections (Table 1). However, few medical facilities were inspected in Finland and Iceland and the results are not considered representative for these countries.

Table 1. Overview of the number and distribution of private and public inspected medical facilities in the Nordic countries. The aggregated numbers from the Nordic countries and Europe is included for comparison.

	DK	FI	IS	NO	SE	Nordic	Europe
Private (%)	33	50	0	37	20	31	44
Public (%)	67	50	100	63	80	69	56
Total No.	15	4	2	19	15	55	148

Procedures for justification

Written procedures covering the justification process (if available) were submitted to the regulatory body to be reviewed in advance of the inspections. Results regarding the availability, knowledge and content of procedures for the justification process are shown in Figure 1 and 2. Most medical facilities in the Nordic countries have procedures describing the justification process (except for Iceland), which are known by relevant staff, implemented in daily work and frequently updated. Non-compliance with national regulations were present to a larger degree in Sweden. In general, procedures for justification were available at a higher degree in the Nordic countries (82%) compared to European countries (55%). However, in many countries where written procedures were missing, some kind of practical routine were established.

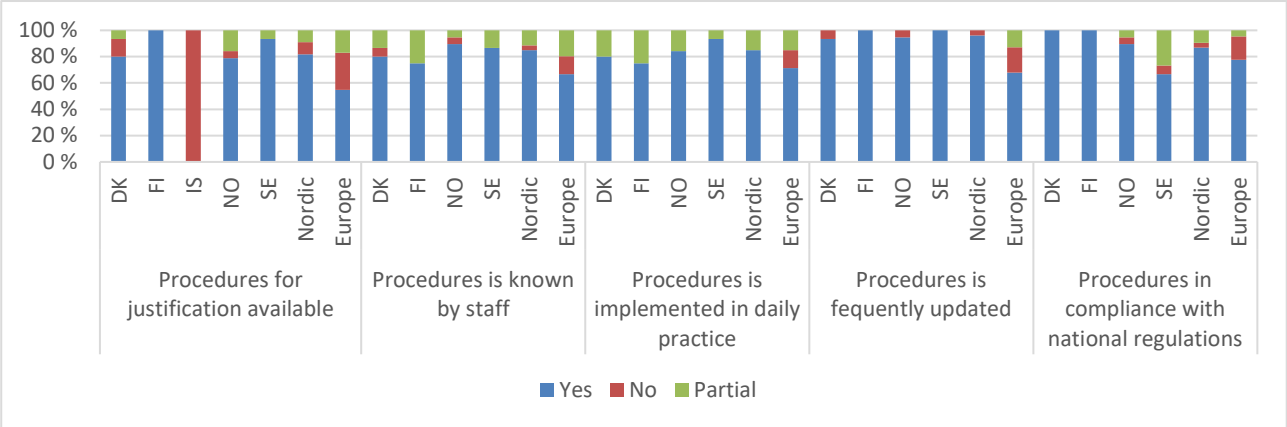

Fig. 1. Summary of the results regarding the availability, knowledge, implementation and revising of the procedures for justification. Iceland had no procedures and are not included in the further analysis in the figure.

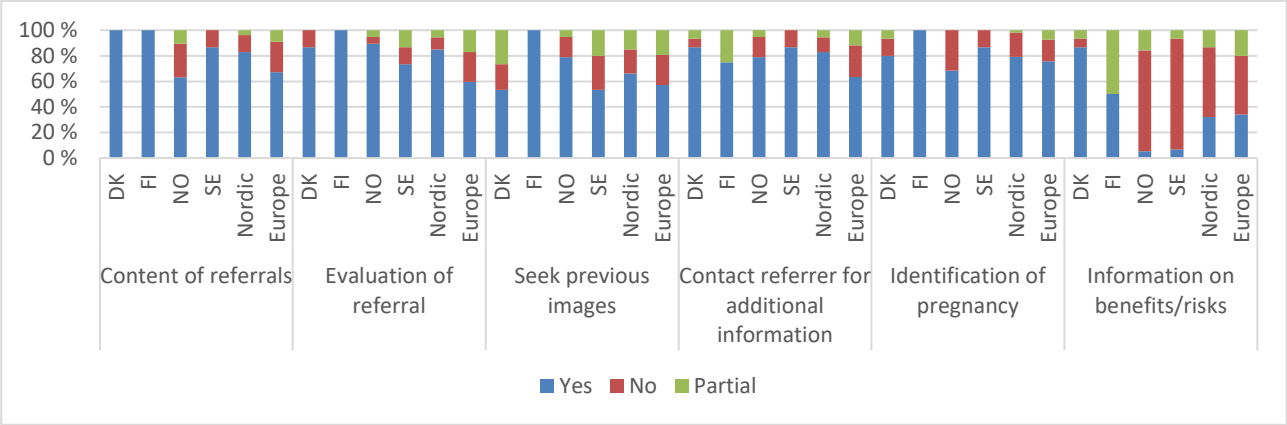

Fig. 2. Summary of the results regarding the coverage of important topics in the procedures for justification.

Most topics identified by HERCA as important to ensure for a proper justification process, were covered to some extent by the available procedures (figure 2). However, information to patients about benefits and risks was poorly addressed in most procedures in Norway and Sweden and in general in Europe.

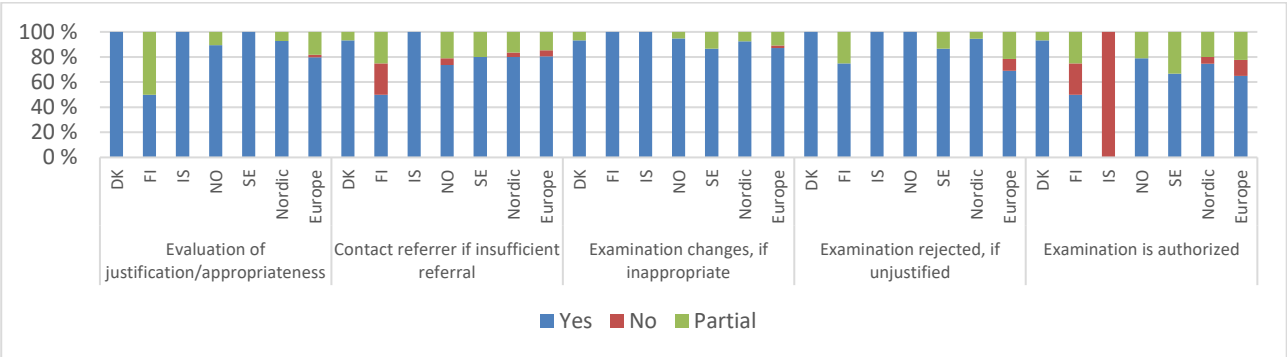

Fig. 3. Summary of the results regarding the daily practice on evaluation of referrals prior to the performance of the examination.

Most of the Nordic facilities had established good practice for evaluation of the referrals before the examinations were performed (se Figure 3). However, still too many inappropriate and unjustified examinations are performed and the practice involving communication with the referrer to obtain additional information must be improved. There is also a need to strengthen the procedures for authorization of medical exposures before they are performed, especially in

Iceland and Finland. Assignment of responsibility and allocation of tasks among staff involved in the justification process (referrers, practitioners, radiographers and booking personnel) were not clearly defined at all facilities. In the Nordic countries, allocated tasks and responsibilities were known by the staff in 87% of the facilities, while delegation of tasks was documented only in 67% of the facilities. The corresponding figures from Europe were 76% and 52% respectively.

Referral guidelines and clinical audit

Most of the inspected facilities in the Nordic countries had available referral guidelines for medical imaging (national, regional or local), except in Iceland and to some extent Norway (figure 4). The referral guidelines are made available to the referrer, however the awareness and use of them are highly unsure in most countries. Very few countries had procedures for clinical audit and clinical audits were seldom performed. Among the Nordic countries, only Finland had fully implemented the concept of clinical audit. In lack of clinical audits, other kinds of audits/revisions of the justification process were present to some extent in 40% of the inspected facilities in Europe.

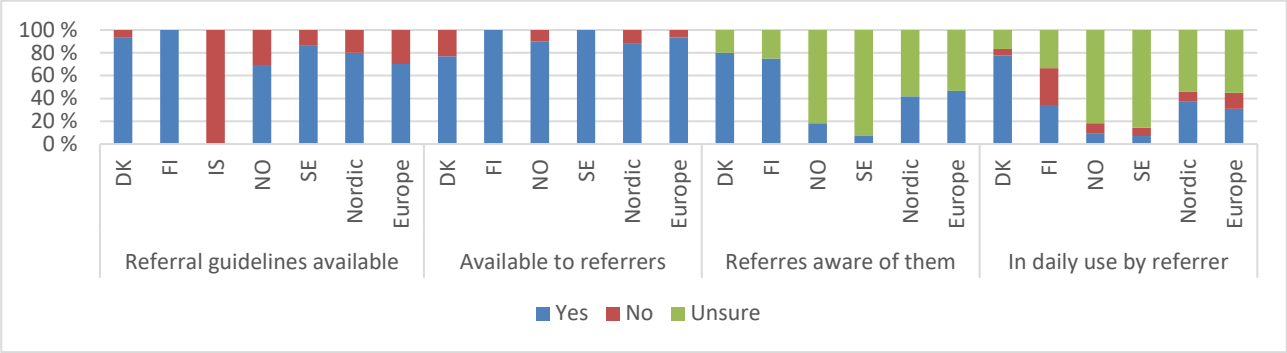

Fig. 4. Summary of the results regarding referral guidelines for medical imaging.

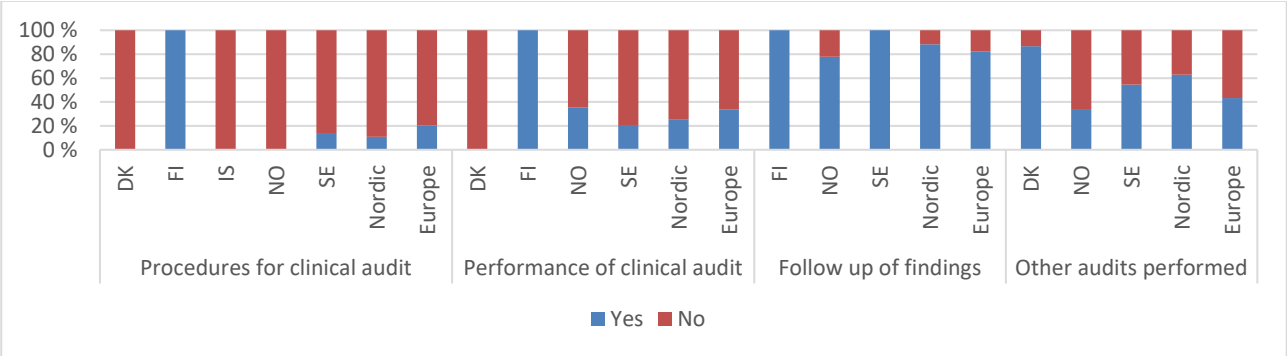

Fig. 5. Summary of the results regarding clinical audit.

Quality of referrals

The presence and overall quality of the referrals are summarized in figure 6 and 7. The quality for the administrative issues of the referrals were mainly good, but contact information to the referrer were missing in some of the referrals. For the practitioner to be able to ensure for proper justification, the overall quality of the referrals when it comes to clinical information should be improved.

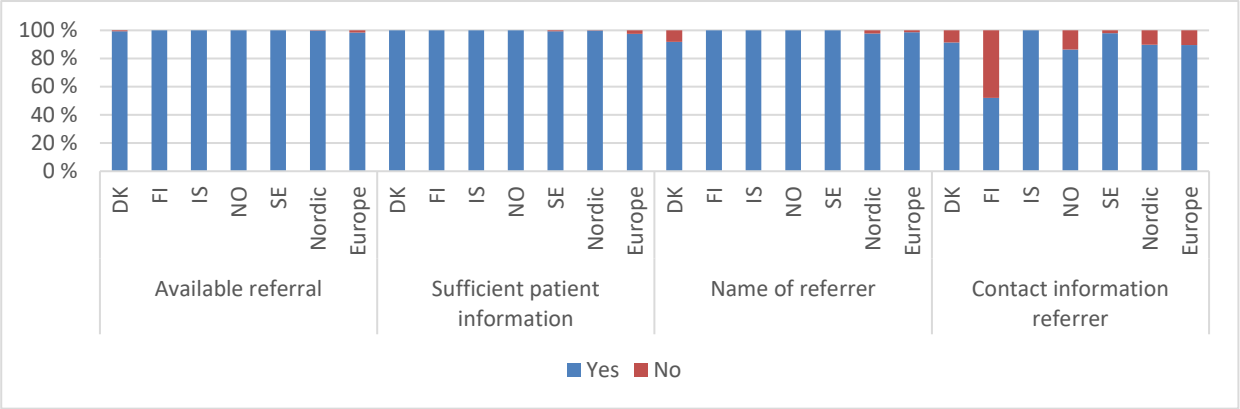

Fig. 6. Summary of the results regarding the quality of the referrals concerning administrative issues.

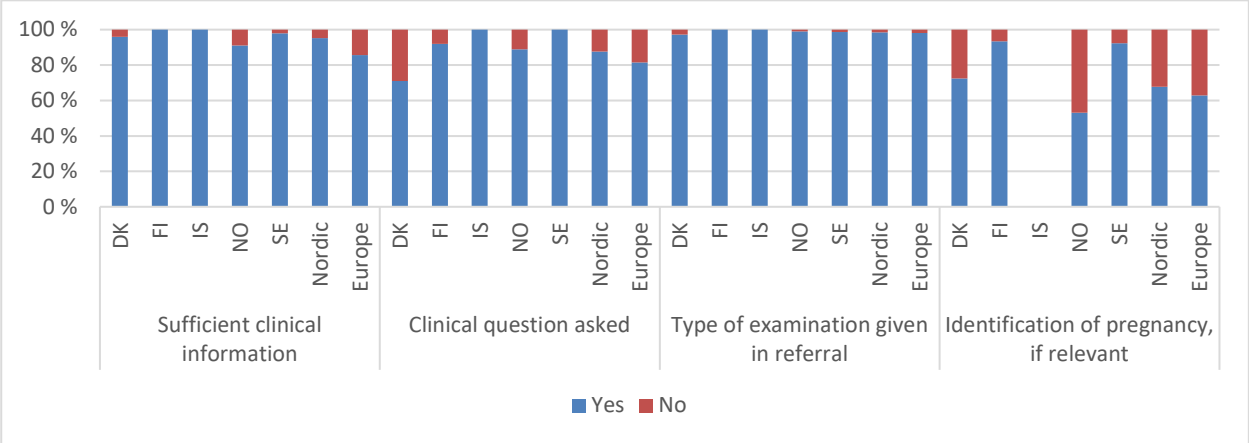

Fig. 7. Summary of the results regarding the quality of the referrals concerning clinical issues.

Conclusions

Implementation of the different steps in the justification process varied among countries. It is important that allocation of responsibilities and tasks associated with justification is recognized by the management, is formalized in procedures and that involved staff receive proper training to take on the assigned tasks and responsibilities. Availability of referral guidelines are still lacking in many countries and the concept of clinical audit is not implemented to a satisfactory level across Europe. There is a need to increase the awareness and to reiterate the importance of the justification process in medical imaging.

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S3-O3

A road-map for developing referral guidelines for diagnostic imaging in the Russian Federation

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Justification of medical exposure is a complex process that is mainly carried out through the implementation of referral guidelines for diagnostic imaging. Since 2016 the Institute of Radiation Hygiene in collaboration with the Ministry of Healthcare of the Russian Federation has been developing proposals for the development of referral guidelines. That included analysis of the existing clinical standards of X-ray diagnostics, their comparison with the international referral systems (iRefer, ACR Appropriateness Criteria, iGuide, etc.), estimation of the radiogenic risk values from common diagnostic X-ray examinations and evaluation of the risk-benefit analysis models. The outcome indicated that admission of the imaging modalities is regulated by 3-5 none-harmonized documents of different rank (standards, recommendations, orders of the Ministry of Healthcare) for each disease category. Hence, the first step of the development of the referral guidelines would be to harmonize the existing regulatory documents, updating them with modern imaging modalities and providing the physicians with information on the diagnostic efficiency, typical effective dose values and radiation risk categories for the common X-ray examinations. The next step is would be to provide more detailed data on the radiation risk, considering age and gender of the patients. Later on, risk-benefit ratios would be assessed for different imaging modalities for different diseases based on the relative risk approach as proposed by IAEA.

S3-P1

Perception of the radiation risk among the Russian specialists in radiation protection

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This study was aimed at the evaluation of the perception of the radiation risk among the Russian specialists in radiation protection (regulators, medical physicists and representatives of the Ministry of Healthcare). The study was conducted among the participants of the Scientific conference "Actual Issues of Radiation Hygiene" that was held in St. Petersburg on October 23-24, 2018. The study was performed with the dedicated questionnaires, containing a set of questions on the attitude towards the use of nuclear energy and risk communication. A total of 137 questionnaires were filled in and returned.

The study indicated that 63,5 % of respondents agreed with linear non-threshold, 17,5 % – hormesis, 9.5 % – threshold theories; 9.5 % provided no direct answer. 68.6 % of respondents considered that nuclear energy should be developed, 16.1 % - reduced if possible; 15.3 % refused to answer. That confirmed the fact that experts generally have a positive attitude towards the development of nuclear energy.
The opinions of experts were divided on the question on the right of the authorities to restrict access to information on environmental consequences and threats to the public in case of a nuclear accident. 43,8% of respondents supported the non-restriction of the information in such case; 56,2% - agreed with the partial or full restriction or non-disclosure.

S4-O1

An on-line system for calculating staff doses - the PODIUM project

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The main aim of the PODIUM project is the development of an online dosimetry application based on computer simulations without the use of physical dosemeters. Real movements of exposed workers captured by tracking tools have been used together with Monte Carlo simulations for the development of the application. The methodology has been applied in two workplaces where improvements in dosimetry are urgently needed: neutron and interventional radiology workplaces. The availability of advanced online dosimetry applications such as these in the radiation protection field will increase awareness among workers and should improve the implementation of the ALARA principle.

This presentation will describe the concept and some experiences using the tool in interventional radiology.

S4-O2

NaCl pellets as prospective dosemeters for hospital applications: preliminary experience from Skåne University Hospital

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Household salt, NaCl, read out by optically stimulated luminescence (OSL), is sensitive to ionising radiation which has led to applications in retrospective OSL dosimetry. Lately, it has been investigated to use the salt for prospective dosimetry as the dosimetric properties of NaCl together with the accessibility could make NaCl an alternative or complement to today's commercially available dosimeters. To simplify handling during measurements and readouts, the NaCl is pressed into a small pellet. The NaCl pellets have a linear dose response up to at least 300 mGy and a detection limit, in terms of minimum detectable doses (MDD), around 10 µGy. The signal fading is negligible over at least 30 days.

As part of the development and testing of a passive dosemeter made from NaCl pellets, dose measurements in different clinical and experimental settings have been performed. For example, pellets were used to measure ambient doses in corridors close to resting PET-patients and to measure finger and hand doses to staff working with radiopharmaceuticals. Finger doses were also estimated by NaCl pellet measurements on nurses who prepare radioactive seeds for brachytherapy. The NaCl pellets were also used for dose mapping of the surgeons during fluoroscopy. Test have also been performed on phantoms during computer tomography, as well as for environmental monitoring purposes. So far, these tests provide results that are comparable or even more accurate than commercially available similar dosemeter alternatives, encouraging for more widespread investigations and tests.

S4-O3

Spectra Recording Semiconductor Detectors for Medical Imaging

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In X-ray imaging, detectors capable of recording the energy of the detected photons, so called photon counting (PC) detectors, could give more precise information of the anatomical structures inside the patient. The spectra collected from each pixel of the detector can be used to examine the absorption of photons at multiple energies, thus giving an advantage over conventional imaging devices. The additional information from detected photons with PC detectors would lead to lower doses. However, medical imaging detectors capable of recording photon energies accurately do not yet exist.

Pixelated PC detectors are developed in a collaboration between HIP, LUT University, Aalto University and STUK. Detector materials under investigation are CdTe, CdZnTe and scintillator enhanced silicon (SiS). The detector signal is read out with a read out chip (ROC) developed for the CMS experiment at CERN. The ROC is capable of recording spectra from each pixel of the detector.

A CdTe detector was tested in a Cs-137 beam. The resolution of the 662 keV peak was 2%, which indicates desirable characteristics at X-ray imaging energies. The current induced by radiation through Si diodes with and without scintillator coating were measured in RQR quality X-ray beams. The current was higher with the SiS detectors from RQR4 onwards (tube potential 60 kV). The pulse mode operation of the SiS detectors is under investigation and the coating method will be applied to pixelated Si detectors.

S4-O4

Ionizing radiation detection with mobile phones

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Introduction

There are tens of applications that convert a mobile phone to an ionizing radiation detector. These applications can be downloaded for free or for a small amount of money. There are basically two different methods in detecting ionizing radiation with mobile phones. One is a separate semiconductor detector converting radiation to pulses that are sent to mobile phone. Another method is using the mobile phone camera of the mobile phone. Lens must be covered with black tape to prevent visible light photons getting to the CMOS sensor of the camera

STUK has received questions from citizens concerning the reliability of these mobile phone detection applications. Therefore, STUK has tested some popular ionizing radiation detection mobile phone applications based on both techniques.

Purpose

The purpose of this study is to test mobile phone radiation detectors in order to investigate how reliable they are for measuring radiation.

Methods

The tests were performed in the Finnish National Metrology Laboratory in STUK. Tested applications were Smart Geiger Pro (external semiconductor probe), Smart Geiger (external semiconductor probe), GammaPix (camera) and Radioactivity Counter (camera). Applications were designed to measure low dose rates of X ray and gamma radiation. Used radiation quantity were ambient dose equivalent rate $\dot{H}^*(10)$. Test program consisted the calibration for dose rate, linearity, energy response in the range of 59.5-1250 keV, repeatability and testing the overflow features.

Results and discussion

<u>Test results</u>

Applications were tested for linearity, energy response, repeatability and overflow feature. Here are the test results for four different mobile phone detector types.

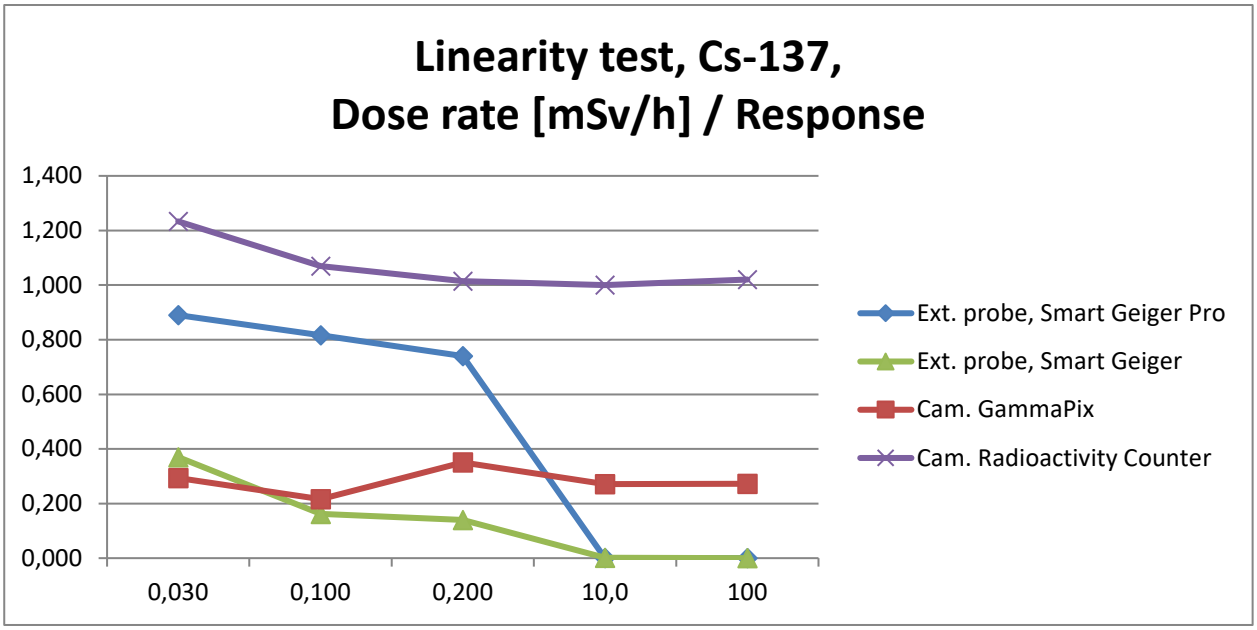

Fig. 1. Linearity test results.

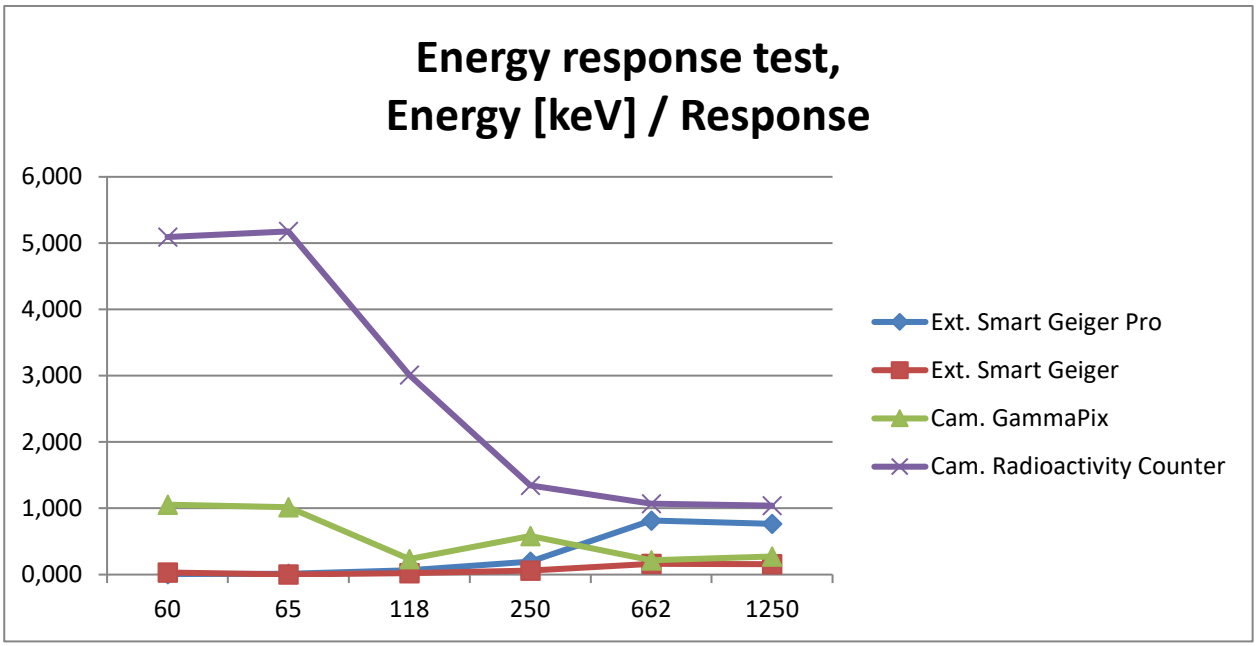

Fig.2. Energy response test results.

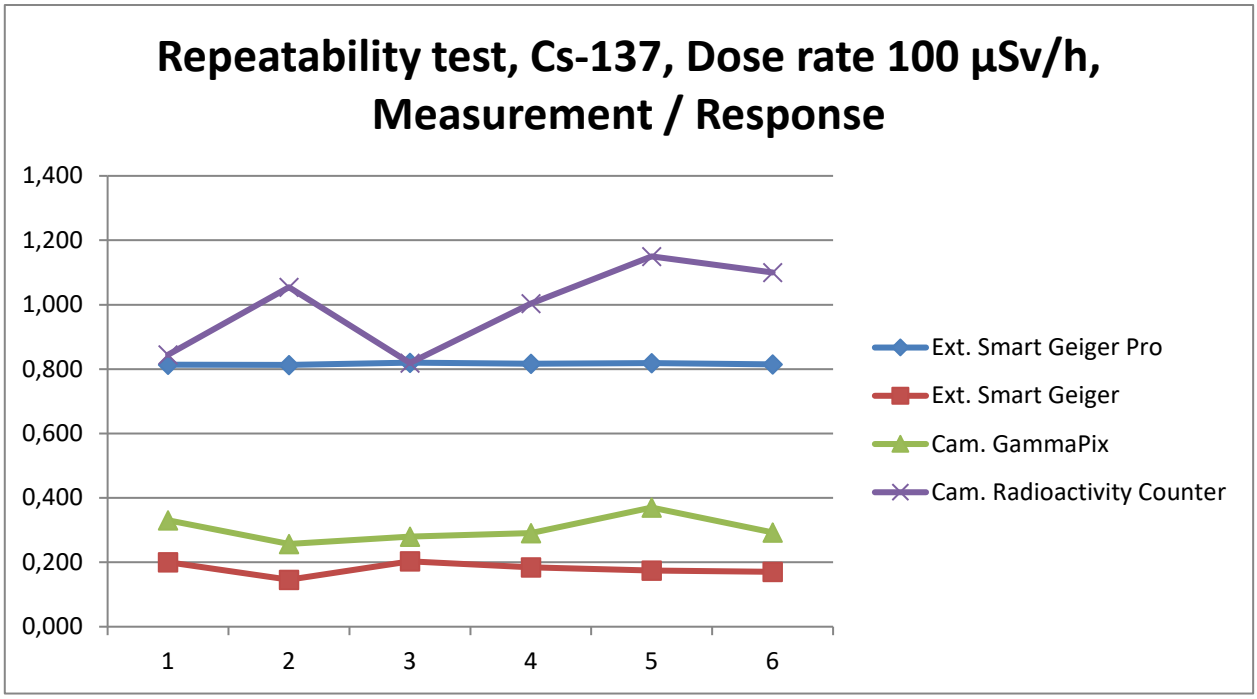

Fig.3. Repeatability test results.

Fig. 4. Mobile phone applications, Smart Geiger Pro (right), Smert Geiger (left) and GammaPix (down).

Table 1. Test results of linearity, energy response and repeatability.

Radiation quality	Energy [keV]	Reference dose rate $\dot{H}^*(10)$ [mSv/h]	Smart Geiger Pro	Smart Geiger	GammaPix	Radioactivity Counter
^{137}Cs	662	0.030	0.890	0.370	0.293	1.233
^{137}Cs	662	0.100	0.816	0.162	0.216	1.070
^{137}Cs	662	0.200	0.740	0.140	0.351	1.015
^{137}Cs	662	10.0	0.000 [1]	0.000 [1]	0.271	1.000
^{137}Cs	662	100	0.000 [1]	0.000 [1]	0.272	1.020
^{241}Am	59,5	0.072	0.008	0.031	1.055	5.090
ISO N-80	65,0	0.130	0.012	0.002	1.015	5.177
ISO N-150	118	0.195	0.067	0.023	0.235	3.010
ISO N-300	250	0.150	0.197	0.061	0.584	1.345
^{137}Cs	662	0.100	0.816	0.162	0.216	1.070
^{60}Co	662	0.100	0.767	0.155	0.274	1.040
^{137}Cs	662	0.100	0,814	0.200	0.331	0.844
^{137}Cs	662	0.100	0,813	0.146	0.257	1.054
^{137}Cs	662	0.100	0,820	0.203	0.280	0.819
^{137}Cs	662	0.100	0,817	0.184	0.291	1.004
^{137}Cs	662	0.100	0,819	0.174	0.370	1.150
^{137}Cs	662	0.100	0,815	0.170	0.293	1.100

[1] Dose rate over the dose rate measurement range. Meter didn´t express overflow. Test failed.

Conclusions

To summarize the test results, it can be stated that mobile phone ionizing radiation applications can detect radiation, but the measurement results are not very reliable. Overflow feature failed for other applications except Radioactivity Counter. In addition, some of the tested applications were sensitive to external interference such as Wi-Fi and static electricity. It was also noted that measurement results depend on the model of the mobile phone. Radioactivity Counter seems so be most reliable application based on the test results.

S4-P1

Evaluating or reducing the conservativeness of dose estimations

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Introduction

Being conservative, when estimating doses or consequences in a safety analysis, is a common strategy to cope with the inherent uncertainties met in radiation protection. Although this approach may be safe it might not be optimal in the sense that the degree of conservatism cannot easily be determined, and therefore there is a risk of being over conservative, resulting in an economical penalty. A radiation protection expert must be able to assess and cope with uncertainties, instead of always employing the "let us better be safe and conservative" approach. A simple strategy to cope with uncertain parameters is proposed in this abstract.

Purpose

The proposed method provides an alternative to just being conservative when uncertainty is met. Furthermore by using expanded uncertainties the method gives a means to quantify how conservative the resulting estimation is.

Methods

It is often that one encounters parameters whose values are unknown when calculation doses. In these cases one tends to use worst case scenarios to determine values used in the calculations. Although not as simple one could also try refrain from using worst case scenarios and use the proposed method. Basically the method, which relies on probability distribution functions, is related to the use of worst case scenario values. Because one has to assess that a case is a worst case scenario. I.e. the probabilities of finding worse cases are negligible. So instead of determining the worst case value one should try to establish a probability function. And then use the expectation value as the working parameter along with the variance of the of the probability distribution function. The square root of the variances is then used as standard deviations and propagated using the law of propagation of uncertainties [1]. Finally the result can be an expanded uncertainty which inherently gives quantification how conservative the estimation is in the form of a confidence.

The most simple probability distribution function is the uniform distribution; however in this abstract the lognormal and the two parameter Weibull distribution functions are used. As both of these functions are defined by two parameters, the procedure is identical for both.

Assuming that a given parameter is distributed by either the Weibull or lognormal distributions the task is to determine the defining parameters of the distribution one would like to use. The starting point could be the worst case value one would have used. This value along with an assessment of the confidence value is the first step of this method. The confidence value is simply the value of the cumulative distribution function at the worst case value. Most often when assessing the possible values one can think of a less conservative value which one think is a very likely value, but due to the uncertainties the worst case value is most often picked. However this likely value could be taken as the mode of the distribution function. From the assessment procedure given above one has the necessary information to establish the distribution function.

Weibull [2]. For all $x \geq 0$ the Weibull distribution function is given as:

$$f(x;\lambda,k) = \frac{k}{\lambda}\left(\frac{x}{\lambda}\right)^{k-1} e^{-\left(\frac{x}{\lambda}\right)^{k}}$$

As the conservative guess, x_2, and the corresponding confidence level, c, are given, an expression relating the parameters λ and k to x_2 and c can be written by the:

$$c = 1 - e^{-\left(\frac{x_2}{\lambda}\right)^k}$$

The likely guess, x_1, combined with the expression for the mode of the distribution gives:

$$x_1 = \lambda\left(\frac{k-1}{k}\right)^{\frac{1}{k}}$$

Combining the two equations a transcendental equation which has to be solved in order to determine k.

$$x_1^k ln(1-c) + x_2^k\left(\frac{k-1}{k}\right) = 0$$

Once k has been determined λ can be easily found using one of the expressions above. The expectation value is $E(x) = \lambda \cdot \Gamma\left(1+\frac{1}{k}\right)$ and the standard deviation

$$U(x) = \lambda\sqrt{\Gamma\left(1+\frac{2}{k}\right) - \Gamma\left(1+\frac{1}{k}\right)^2}.$$

Lognormal [3]. For all $x \geq 0$ the lognormal distribution function is given as:

$$f(x;\mu,\sigma^2) = \frac{1}{x\cdot\sigma\cdot\sqrt{2\pi}}\, e^{-\left(\frac{\ln(x)-\mu}{\sqrt{2}\sigma}\right)^2}$$

Following the procedure given in the case with the Weibull distribution, the conservative guess, x_2, and the corresponding confidence level, c, are given. An expression relating the parameters μ and σ^2 to x_2 and c can thus be written:

$$c = \frac{1}{2}\left(1 + erf\left(\frac{\ln(x)-\mu}{\sqrt{2}\sigma}\right)\right)$$

The likely guess, x_1, combined with the expression for the mode of the distribution gives:

$$x_1 = e^{\mu-\sigma^2}$$

Combining the two equations the maximum of the roots of a quadratic function has to be determined in order to determine σ.

$$\sigma^2 + \sqrt{2}\,\mathrm{erf}^{-1}(2\cdot c - 1)\sigma + ln\left(\frac{x_1}{x_2}\right) = 0$$

Once σ has been determined μ can be easily found using one of the expressions above. The expectation value is $E(x) = e^{\left(\mu+\frac{\sigma^2}{2}\right)}$ and the standard deviation $U(x) = \sqrt{\left(e^{\sigma^2}-1\right)e^{2\mu+\sigma^2}}$.

Once the distribution has been determined one might use it in a Monte Carlo simulation or just use the expectation value and the standard deviation.

Results and discussion

An example showing the feasibility of the method is given below. A parameter is unknown and needs to be assessed in order to do a calculation. A worst case scenario case gives $x_2 = 75$ but $x_1 = 25$ is assumed to be most likely. The confidence level is estimated to be either 95% or 99.5%.

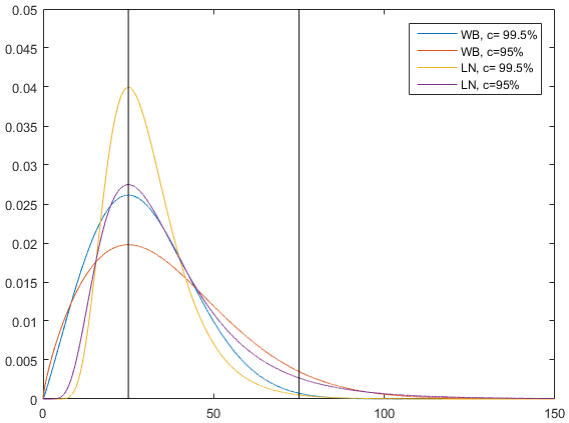

Fig. 1. The Weibull and lognormal probability distribution functions for the two confidence levels are shown.

Figure 1 shows the probability distribution functions for the different cases. The two vertical lines are the guessed values. For the case were $c = 95\%$ the expectation values are $E_{WB} = 38(22)$ and $E_{LN} = 37(16)$. For the other case, where $c = 99.5\%$, the expectation values are $E_{WB} = 29(13)$ and $E_{LN} = 31(10)$. For the same confidence level the values from the two distributions are more or less the same.

Conclusions

A simple method is proposed, to cope with uncertainties in parameters using Weibull and log normal distributions. This method provides an evaluation of the conservatism given in the calculations through the propagation of uncertainties and expanded uncertainties. This method lends itself for more elaborate Monte Carlo simulations and simple hand calculations.

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S5-O1

Radiation protection of patient in cardiology

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Fluoroscopic methods play an integral role in contemporary interventional cardiology. Their amount increases in Finland at a rate of 10 % a year. In particular, the aging population increases the demand for those kind of procedures. Simultaneously, the technological advances (such as improved image quality or reduced frame rates) enable lower radiation doses for patients and operators. However this is in itself not enough to satisfy ALARA principle, especially that procedures are often performed by cardiologists, whose knowledge on radiation protection, physics and technology might not be as profound as that of specialized radiologists.

The radiation protection of patient plays in integral role in interventional cardiology, as the patient's dose is directly related to stuff dose. The basic (such as use of fluoroscopy and cine-imaging) and more advanced (such as usage of grids or digital zoom) are presented. The effect of imaging directions on the dose is pondered. The staff dose optimisation techniques are similar to those used in other interventional procedures (such as lead aprons, mobile lead barriers, table shields or minimizing the amount of staff in the operational theatre), however their application may vary depending on a cardiological procedure. The effective use of those techniques in several cardiological procedures (such as coronary angiography, percutaneous coronary intervention, or Transcatheter Aortic Valve Implantation (TAVI) procedures) are explored. Radiation protection during resuscitation is presented. The issues concerning protection of pregnant workers are pondered.

S5-O2

Radiation protection of staff in cardiology and interventional radiology

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Abstract

Radiation protection of staff plays an important role in cardiology and interventional radiology because workers are usually unable to move away from angiolaboratory during the procedures. Cardiologist and interventional radiologist are among leading users of ionizing radiation and do receive the yearly biggest measured radiation dose for medical usage. In addition, other staff working in angiolaboratory (e.g. nurses, anesthesia, surgery, company representatives) can have the dose during procedures.

Several factors affect the total dose of workers, which are partly the same as the factors affecting the patient dose. For angiolaboratory stuff, it is imperative to safeguard against ionizing radiation by wearing radiation protective clothes. Furthermore, lead glasses are important, especially for cardiologists and interventional radiologists. Protective clothing, when used properly, makes a difference of 1/10 or even 1/30. Modern X-ray systems are capable of providing excellent image quality with lower X-ray exposure than before. However, radiation remains a risk for procedure personnel and patients despite these improvements.

Radiation and Nuclear Safety Authority in Finland (STUK) published 2018 a 100-page long leaflet "Radiation safety in Cardiology" (in Finnish: “Säteilyn käytön turvallisuus kardiologiassa”) that explored the optimization techniques in several cardiological procedures, such as coronary coranary angiography, percutaneous coronary interventions as well as Transcatheter Aortic Valve Implantation (TAVI) procedures. In this leaflet, the radiation protection of staff encompasses several topics not only involving shielding, but also those relating to instructions for operators on how to use angiography device in an optimal manner also from the point of radiation.

Introduction

Radiation and Nuclear Safety Authority in Finland (STUK) published 2018 a 100-pages long leaflet "Radiation safety in Cardiology" [1] that explores the optimization techniques in several cardiological procedures, such as coronary coranary angiography, percutaneous coronary interventions as well as Transcatheter Aortic Valve Implantation (TAVI) procedures. In this leaflet, radiation protection of staff was also covered and for example thigs like taking a backward step from radiation source whenever possible and use radiation shields always when possible. Also instructions for operator to use angiography device in an optimal way from the standpoint of radiation protection were also presented. It is important to remember that pregnant women should not work in angiography lab in order to safeguard their unborn child. In addition, young people below the age of 18 do not work in angiolab as they are more vulnerable to radiation risks.

Purpose

In medical diagnostics and treatments, cardiology and interventional radiology is witnessing a growing demand in Finland because the mean age of patients cardiac angiography and PCI is almost 70 years and the number of these aged groups is on the rise. It is estimated that age group of 75+ will almost double in the next 15 years. Despite the growing number of diagnosic coronary angiography and PCI treatments, the dose levels of staff working in angiolaboratorios can be reduced because Modern X-ray systems are capable of providing excellent image quality with lower X-ray exposure. Also, the proper use of lead aprons, mobile lead barriers and e.g. table shields will minimize scattered radiation from patients and lower the dose for staff. The number of staff in the operational theatre should also be “as low as possible” but may vary depending on the cardiological procedure.

Methods

In the leaflet “Radiation safety in Cardiology" [1], several aspects of radiation protection are considered. Lead aprons (X-ray vest, skirt, thyroid shield, with lead equivalents of 0.25 or more mmPb) signify the most important protection method from scattered radiation and, when properly used, can reduce the effective dose of staff at factor 1/10 or even 1/30. Lead aprons should be worn by everyone in a fluoroscopy room (with the exception of the patient). Depending on the energy of the X-rays (kV setting) and the lead equivalent thickness of the apron, lead aprons may reduce the dose received by over 90% (85%-99%). A wrap-around lead apron with 0.25 mm lead equivalence that overlaps on the front provides 0.25+0.25=0.5 mm lead equivalence on the front and 0.25 mm on the back would be ideal in this regard [2]. In addition, lead glasses are important, especially for cardiologists and interventional radiologists.

Radiation measurement can give an estimation of staff dose. Personal dosimeters such as TLD (thermoluminescent) -based or DIS (direct ion storage) -based measurement units could be placed e.g. in thyroid shield or in x-ray vest facing the radiation source. In addition, measurement devices that provide real-time information of dose levels could help staff to obtain a better understanding of the amount of radiation in operating room and possibly give out the information that even one step backwards from radiation source can lower the dose level to one fourth.

Angiography devices have table shields as well as upper shields in order to safeguard the operator and have a significant impact on the total scattered radiation in the operating room. In upper shield, it is a good idea to use drapes to have the shield firmly fit to patients’ body which prevents radiation from being scattered from patients imaging area. Also, disposable or non-disposable radiation protection drapes can be used with the upper shield and can reduce the phenomenon of radiation scattering [3]. It is also a good idea to have scattering maps from the operating room to provide a better understanding of the effects of x-ray protection shields in the operating room for the staff (Fig 1.).

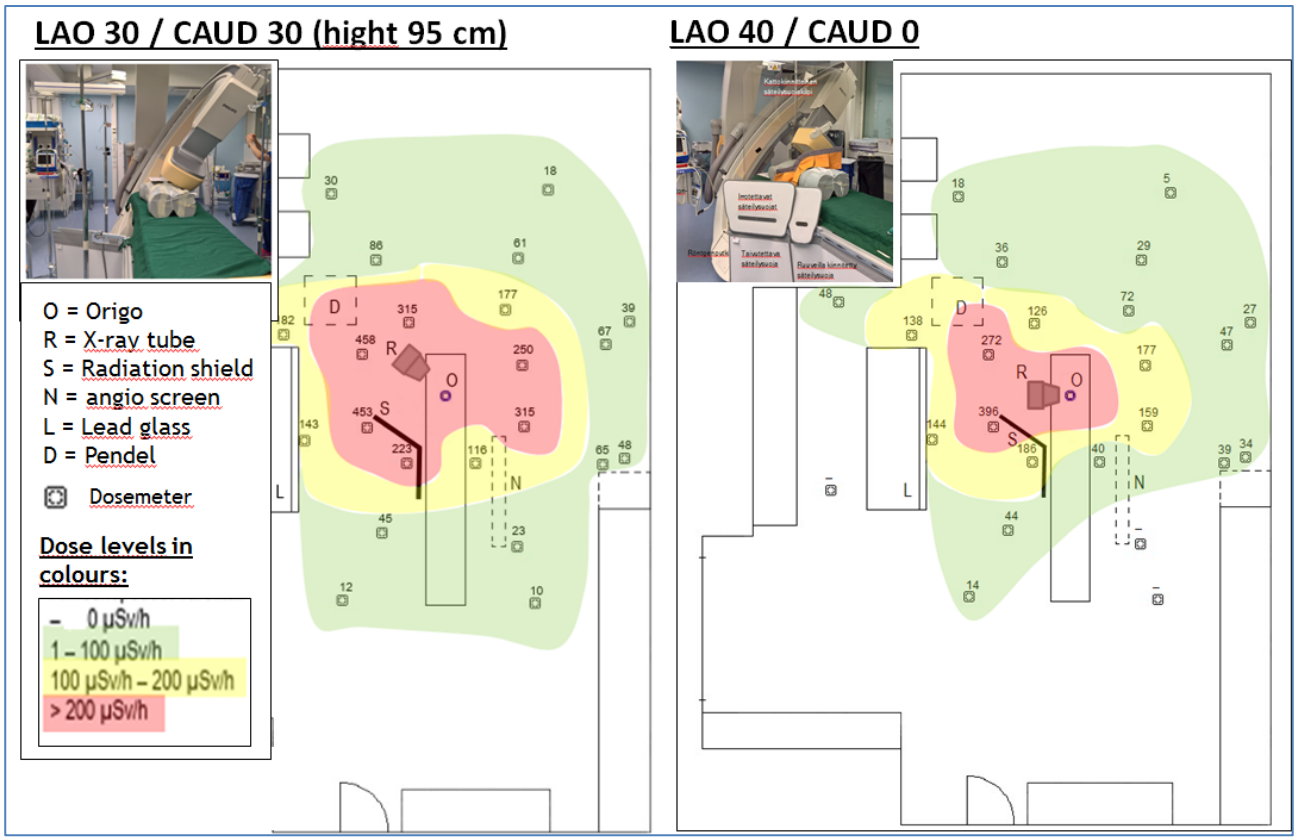

Fig. 1. X-ray radiation scatter maps from angiolaboratory at two projections LAO 30 / CAUD 30 (left) and LAO 40 / CAUD 0 (right) [4].

In Fig 1. there were more scattered radiation visible in maps which were done on the basis of more oblique projections which was the LAO 30 / CAUD 30 (left) compared at LAO 40 / 0 (right) which did not have caudal angulation and therefore was less oblique than the aforementioned projection.

In fluoroscopy, it is important for cardiologists and interventional radiologists to identify and employ the projections which provide a good quality image with minimal radiation dose (ALARA). Evidently, the cardiologists and interventional radiologists' expertise influences the patient's radiation exposure in a manner which allow the procedures to be of a shorter duration with more experienced users. The PA views and RAO views >or=40 degrees should be favored over steep LAO projections >or=40 degrees, whenever possible [5]. Tube angulations that are radiation intensive to the patient are also known to increase the operator's radiation risk.

Results and discussion

To reiterate the basic rules of radiation shielding, it is a good idea to have IAEA poster "10 Pearls: Radiation protection of staff in fluoroscopy" [6] visible in every angiolaboratory. This poster is currently translated into 28 languages. IAEAs ten thumb rules include remainding to use protective devices as well as to make good use of time-distance-shielding (TDS) principle. The use of ceiling suspended screens, lateral shields and table curtains is addressed and it is also reminded to keep hands outside of the primary beam unless it is totally unavoidable. It is normally better to stand on the side of the transmitted beam (i.e. by the detector), which contains only 1-5% of the incident radiation. It is important to keep the X-ray tube under the patients table (when possible) and not over it. It is also important to keep updating knowledge about radiation protection and address

any palpable concerns about radiation protection to protect protection specialists such as medical physicists.

In the leaflet, “Radiation safety in Cardiology" [1], the nine “rule of thumbs” primarily for the operator are
1) Avoid unnecessary staying beside the x-ray tube. Take a step backwards from imaging area (x-ray tube), whenever possible. Use and stay behind the protective shields.
2) Avoid unnecessary fluoroscopy- and image series
3) Set pulse and imaging frequencies as low as possible
4) Set x-ray tube as far away from the patients’ table as possible (by rising patient table)
5) Avoid steep angles while imaging. Instead, use RAO- rather than LAO-projections
6) Set image intensifier as close to the patient as possible. Lowest scattered radiation doses are typically at the image intensifier side of table.
7) Avoid unnecessary zooming during fluoroscopy and angio-imaging.
8) Collimate imaging area as effectively as possible
9) Set upper shield to the surface of patient as properly as possible.

Conclusions

Although modern X-ray systems are able to provide excellent image quality with lower X-ray exposure than before, the risk pertaining to radiation for procedure staff and patients remains. Imaging parameters and projection angles not only impacts patients’ doses, but also the doses of operators and other staff members working in angiolaboratory. It is crucial that stuff working in angiolaboratory wear lead aprons in order to reduce the dose received by over 90%. Finally, it is important to use other protective shields etc. and so as to keep updating knowledge about radiation protection.

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S5-O3

Patient dose variations in cardiology: KAP values and skin doses

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In my research related to 2016 diagnostic reference levels for cardiological procedures in Finland, it became obvious that there is huge interhospital variation in many procedures. This variation is most pronounced in high dose procedures, namely PCIs and TAVIs. In research into the wider situation in EU, it became clear that this variation is even higher in many European countries. In my presentation, I wish to raise awareness to this variation and discuss possible reasons for it.

In addition, I wish to present and discuss the concept of difficulty levels in procedures. As noted in ICRP 103, patient weight alone is not sufficient to explain above variation. As such, I wish to discuss currently ongoing research on the topic – what kind of data is required and what parameters and what methodologies appear relevant. These methodologies currently include multivariate analysis and machine learning algorithms.

With the increasing prevalence of TAVI procedures and published research on their relatively high KAP doses, there is also an interest in what is risk of skin damage such as early transient erythema or worse in contemporary practice in cardiology. In my presentation, I wish to present background and results on gafchromic film dosimetry and relevant related information.

In addition, in recent years various angiosystem manufacturers have been introducing their own skin dosimetry algorithms, which take into account information either unavailable or cumbersome for medical physicists to utilize, such as amount of fluoroscopy and cine from each projection. However, their overall accuracy and independent validation remain mostly unknown. In my presentation, I wish to introduce the most relevant ones and present comparison results to gafchromic film dosimetry for two of them.

Finally, I wish to discuss alert levels and practical methodology for minimizing skin doses. To mention a few, the most common methods are noting the most used projection and minimizing use of cine and zoom in it.

S5-O4

Reporting on Radiation Safety Deviations of Medical X-ray Practices in Finland

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Introduction

Reports to STUK (Radiation and Nuclear Safety Authority) of radiation safety deviations in medical x-ray practices have gone up from 1 to approx. 1000 reported cases per year since 2009 due to promoting the issue, see figures 1 and 2. Since 2015 the majority of reports which concern fairly minor deviations, see figure 2, have been reported annually on a structured form. More prominent deviations are reported with specific case descriptions. The new legislation brings somewhat revised instructions on reporting these deviations 2019 onwards.

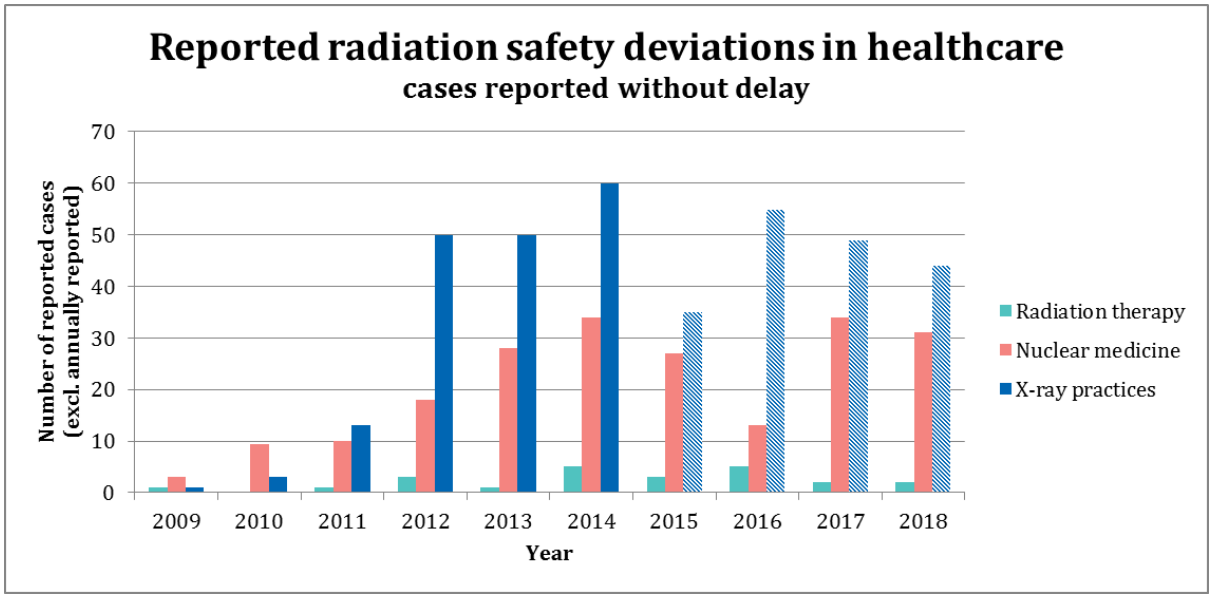

Fig. 1. Trends on numbers of reported cases of radiation safety deviations in healthcare. Cases shown don't include the annually reported minor radiation safety deviations in x-ray practices which were introduced since 2015, see fig. 2.

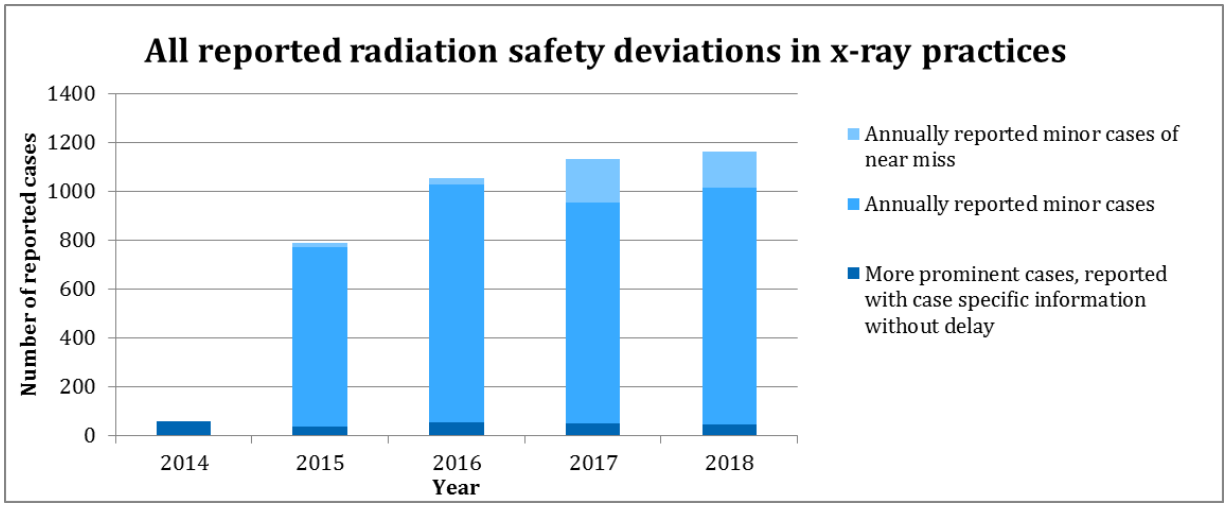

Fig. 2. Addition to fig. 1:s reported cases in x-ray practices including annually reported minor radiation safety deviation cases and so called near miss cases.

Purpose

Reporting of radiation safety deviations (previously called abnormal events) is stated in Finnish radiation safety legislation. Case data presented in this abstract was subject to the previous legislation (Radiation Decree 20.12.1991/1512, Section 17):

"STUK shall be notified of the following without delay:

1. any abnormal event pertaining to the use of radiation that is substantially detrimental to safety at the place where the radiation is used or in its environs,
2. …
3. any other abnormal observation or information of essential significance for the radiation safety of workers or the environment.

The new legislation valid since 15.12.2018 has the same basic idea, but is more comprehensive. In the revised law there is also an addition that other than prominent radiation safety deviations are to be reported to STUK as summarized data.
Report data can be utilized in regulatory control. Gathered data and anonymized cases are for example used also for educational purposes.

Methods

Reported radiation safety deviations, excluding annually reported cases, are recorded in STUK:s licensing registry and each case is handled individually. Statistics from reported cases are drown partly manually.

Structured report form for reporting minor cases of radiation safety deviations was constructed mainly based on reported cases so far and was introduced to be valid 2015 onwards (STUK Guide ST 3.3, appendix D). The structured form comprised of 17 options for categorization of cases and in addition a categorizing option for minor cases of near miss events. Categorization of cases is done by information of who was affected, what happened and the primary cause for the deviation. Additional information is possible to be given in the form.

Results and discussion

<u>Reporting activity</u>

Reporting activity has risen and although not all x-ray clinics send reports to STUK on their radiation safety deviation, reporting activity in year 2018 was at a good level: 100 % of University hospitals, > 70 % of major hospitals, > 50 % of other hospitals and > 30 % of health clinics with radiological department actively send reports. In addition reports were send by a significant portion of private health clinics and some dental clinics.

Compared to total amount of radiological x-ray examinations and procedures, there is 1 reported radiation safety deviation for every 4000 or 5000 examinations or procedures. For the more prominent cases the corresponding ratio is approx. 1 to every 80 000- 100 000.

Statistical findings

One of the most common reasons for radiation safety deviation are malfunctions of either the x-ray device itself or malfunction of related software or other equipment closely related to the examination. Very common reasons are also various human related errors during examination. Radiation safety deviations by type are presented in figures 3 and 4.

One interesting finding is the temporal distribution of radiation safety deviations in healthcare [1]. Not only do human errors appear unevenly during the week with significantly higher incidence on Mondays and Fridays and lower on Thursdays, but the same phenomenon occurs with other, non human errors, with higher incidence in the beginning of the week and on Fridays and lower on Thursdays.

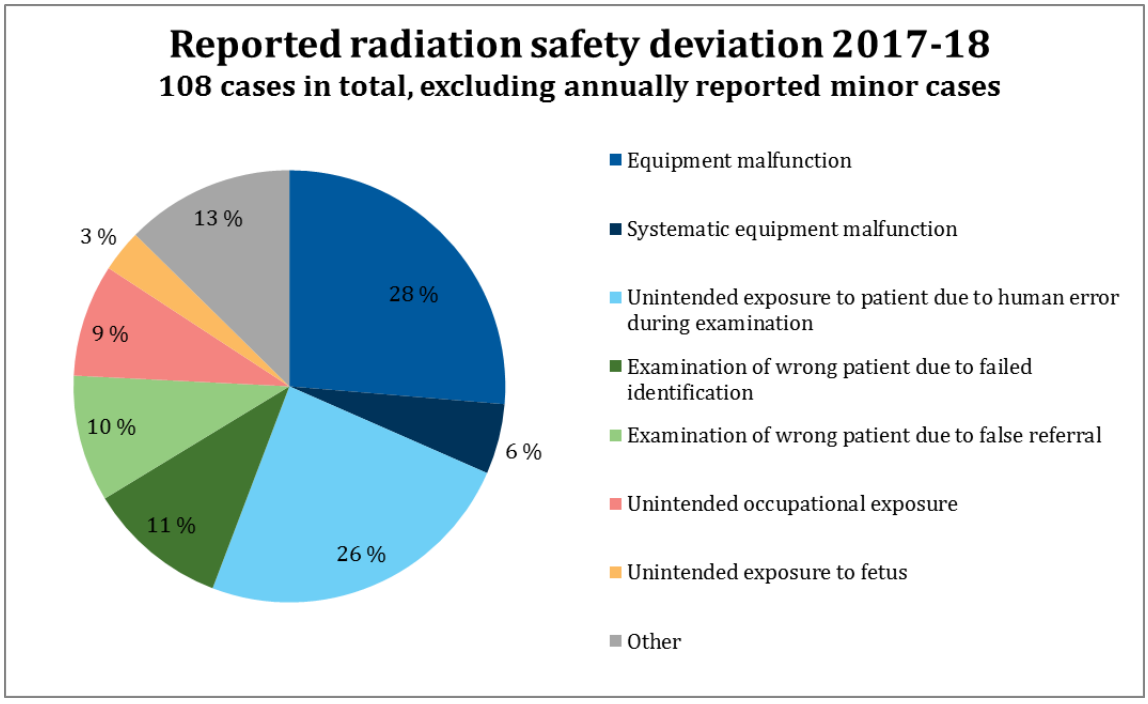

Fig. 3. Distribution of reported radiation safety deviations in x-ray practices by type.

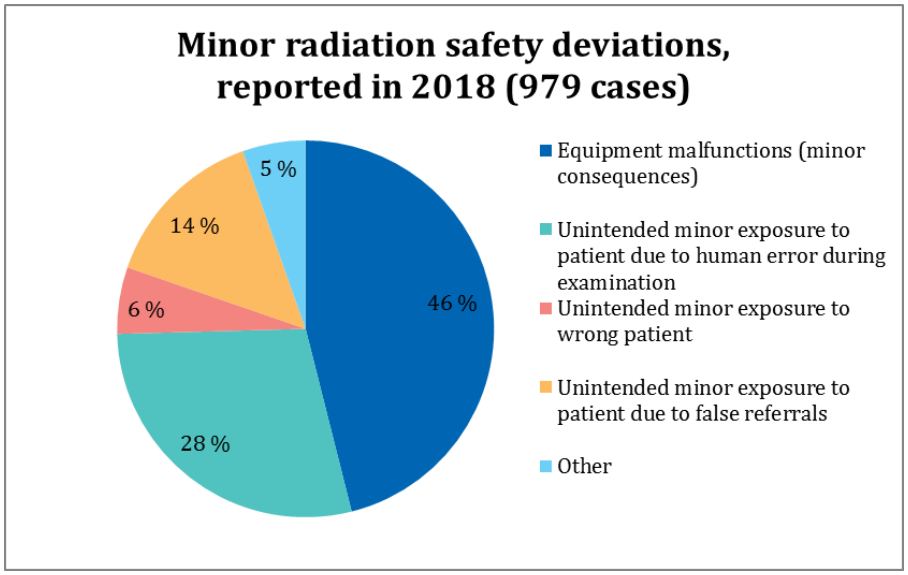

Fig. 4. Distribution of reported minor radiation safety deviations in x-ray practices by type.

Doses related to radiation safety deviations in x-ray practices

High excess doses due to radiation safety deviations in x-ray practices for patients are uncommon, see figure 5. The highest effective doses since 2009 reported have been for patients around 40 mSv. Highest reported unplanned effective doses for fetus has been 34 mSv and for unplanned occupational exposure 80 µSv.

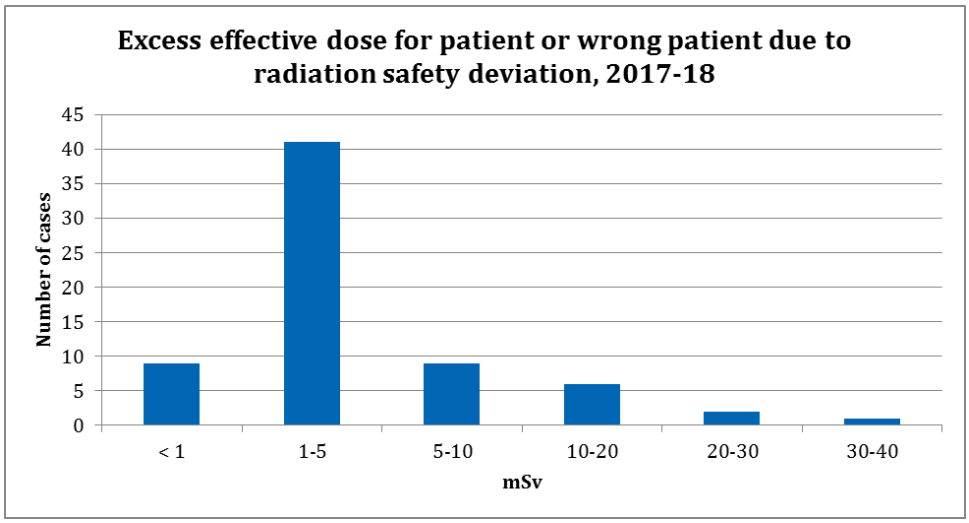

Fig. 5. Distribution of excess effective dose resulted for patients or wrong patients due to radiation safety deviations (excl. annually reported minor safety deviations).

Conclusions

Information coming to STUK regarding radiation safety deviations in x-ray practices in healthcare has risen substantially during the last decade. This indicates recognition and handling of said cases have widespread among x-ray clinics. To draw any conclusions of trends among radiation safety deviations from the data is too early. This is because uncertainties are high due to developed report activity and differences in interpretation among notifiers of which events are actually considered to be radiation safety deviations.

Between 1.1.2015-15.12.2018 only minor cases of x-ray practices were to be reported annually with the structured form including minor cases of unintended occupational exposure. Since introduction of new legislation a STUK order S/2/2018 valid since 1.1.2019 only cases involving medical exposure including minor cases of nuclear medicine are to be reported annually on the structured form. The new improved structured form for reporting minor cases has 28 options for categorizing each case.

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S6-O1

Effective collaboration between authorities and CT Manufacturers on CT dose optimisation

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Tremendous developments in CT technology have taken place over the last few years. The growing use of radiation related to this technology is of great benefit to individual patients and to society as a whole. This has also led to a large increase in medical radiation exposure.
HERCA saw the need for actions to be taken against this increasing trend to higher medical exposures of the European population. It was the firm conviction of HERCA that all stakeholders involved in the radiological process should be part of this important initiative to reduce patient dose. HERCA considered the CT manufacturers to be one of the most important stakeholders in the field of medical radiation protection.
Following a constructive dialogue with HERCA, COCIR and the CT manufacturers agreed to increase their commitment to patient dose reduction through voluntary commitments in 2011:

1. Characterising CT systems standardised benchmarking
2. Implementing dose reduction measures in CT
3. Implementing dose management and reporting tools
4. Providing specific training curricula

The outcomes from these commitments are the design of a reference phantom to objectively quantify head and body Low Contrast Detectability (LCD), the development of a number of dose reduction and management tools that are now available on modern CT scanners and the provision of dedicated training on existing and new dose reduction techniques.
The collaboration between HERCA and COCIR has led to good work being accomplished in CT dose optimisation, management and reporting as well as establishing long term collaboration between COCIR and other stakeholders.

S6-O2

From image quality to care outcome

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Radiology has a long tradition of measuring image quality with objective technical parameters including contrast, noise and resolution, and their derivatives. These parameters have supported our main tasks related to diagnostic process, quality assurance and optimisation. Along with the technical imaging equipment development, the optimisation process has transformed into a more demanding challenge where the image quality metrics should evolve from technical towards clinical representation. This involves medical physicist expertise in combination with radiologist and radiographers in multi-professional collaboration. New methods using radiomics and artificial intelligence (typically deep-learning) enable extension of image quality parameters towards estimating diagnostic accuracy and even predicting care outcome. Comprehensive methodology to enable this approach involves combining several types of data together as a large-scale multi-dimensional data. Deep-learning methods are wellsuited for this kind of data analysis, with inherent non-linearity of the tasks and a large amount of heterogeneous data which is not equitable by traditional methods. We are facing a huge transformation with the development of AI methods in healthcare (as in other areas of life). Research and development is increasing exponentially in this field. The roles and competence of medical physicists and also other healthcare professionals should follow this significant development and incorporate AI and deep-learning topics accordingly into our educational programs.

S6-O3

Nordic guidelines for dose reduction to radiosensitive organs of the patient in conventional radiography and fluoroscopy

The Nordic Radiation Protection co-operation

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5. *STUK - Radiation and Nuclear Safety Authority*
6. *Icelandic Radiation Safety Authority*

Introduction

These Nordic guidelines are written to emphasize the value of appropriate technique for patient radiation dose reduction in conventional radiology and fluoroscopy.

Given that all examinations have been properly justified, and image receptor exposure is optimized based on evaluation of image quality, the following should be considered in order to reduce radiation doses to radiosensitive organs.

The aim of keeping the radiation doses as low as reasonably achievably (ALARA) is to minimize the risk for stochastic effects and tissue reactions. The general approach is to use appropriate radiographic technique and equipment. However, the ALARA approach has to be customized for the individual patient.

PA projections

PA projections are in most cases the best projection for reducing dose to many of the radiosensitive organs. Since only about 1 % of the incident radiation to the patient will reach the detector, dose will be reduced significantly to organs on the ventral side compared to AP projections. In some cases, the use of PA projections will also compress the body to some degree, thus reducing the dose.

In the latest main publication from the ICRP, some of the tissue weighting factors (W_T) were revised [1]. The W_T for breast glandular tissue increased from 0.05 to 0.12, indicating more than a doubling of the previously assumed radio sensitivity. The W_T is an average over the whole population (both sexes and all ages), and since it is in general females that develop breast cancer, the true W_T will be higher for females and especially for female teenagers.

In 2012, ICRP recommended to decrease the annual dose limit for the lens of the eyes from 150 mSv/year to 20 mSv/year for exposed staff, due to new knowledge about radiation induced cataract [2].

Special attention – In some organs, like breast glandular tissue and eye lens, the dose reduction will be significant in PA projections. Special attention should be taken e.g. for female scoliosis patients in their teens.

Collimation of the radiation field

A strict collimation to the area of interest will reduce the dose to neighboring organs. A smaller radiation field will also generate less scattered radiation, benefitting both the patient and any staff standing close to the patient. A strict collimation will also result in a reduced need for shielding of radiosensitive organs, due to the increased distance to other organs. Another important benefit is the increase in image quality, due to the reduced scattered radiation and hence the enhanced contrast.

In dentistry, a rectangular collimator reduces the dose to patients, since the collimation will be restricted to the area of interest.

Special attention: Appropriate knowledge of age related anatomy is especially important in pediatric imaging.

Scatter radiation grid

The use of a grid increases contrast but also increases the radiation dose to the patient by a factor of approximately 3.

When imaging small children, a grid is usually not needed, because of the relatively small amount of scatter produced in the exposed volume.

Compression

The use of compression is an effective dose reduction technique, routinely used in mammography. The technique was more common for other applications earlier, but new and more effective compression equipment on the market have highlighted the technique again. The compression technique is most usable when imaging pelvis, lumbar spine and non-acute abdomen. The half-value layer (HVL) in human tissue is about 3 cm in diagnostic radiology. Most of the patients can be compressed by 7-8 cm in the abdominal area, without feeling any major discomfort [3]. A compression of 6 cm (2 HVL) will reduce the dose by about 75 %. The compression equipment can also be used for immobilizing the patient, thus avoiding blurry images or poorly centered images due to movement.

Gonad shielding

The main goal of shielding gonads are to reduce the risk of hereditary effects. The recent ICRP publication 103 has however, reduced the risk estimates for hereditary effects by a factor of 6-8 [1]. This reduction in risk is reflected in the significant decreased tissue weighting factor for the gonads, from 0.20 to 0.08.

Males

Shielding of male gonads are easy to perform in many cases, and should be performed if the gonads are in the radiation field or closer than 5 cm. The shielding should be done with dedicated shielding equipment, suited for the actual age and size of the patient. When using properly adjusted capsules, the absorbed dose in the testes can be reduced up to 95 % [4]. Shielding should

not be performed if this could compromise visualization of structures of clinical interest or interfere with AEC, thus increasing the risk for re-takes or increased dose.

Females
Shielding of the female gonads are less beneficial, especially for younger females. A dose reduction up to about 50 % may be achieved, if the shielding is applied correctly. However, the location of the female gonads can vary significantly, so the dose reduction in many cases will be much smaller than 50 % [5]. In addition, the risk associated with the potential loss of diagnostic information, resulting in retakes, often outweigh the benefit of gonad shielding. This is more likely for small children and teenagers.

Using the other described dose reduction techniques in an appropriate way, will usually have a larger impact on the gonad dose of the female patient.

Pregnancy

The radiographer shall verify pregnancy status before the examination starts. The verification can be limited to examinations where the pelvic area are exposed, since the fetal exposure will be low for other examinations.

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S6-O4

Harmonization of radiation protection, imaging and dosimetry practices of I-131 therapy in Finland

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Introduction:

I-131 therapy is globally the most common radionuclide treatment. It is used to treat patients with hyperthyroidism or residual thyroid cancer and its metastases after total or subtotal thyroidectomy. The I-131 therapies involve carefully implemented radiation protection and after therapy imaging procedures.

Material and methods:

Our aim is to harmonize the I-131 therapy practices in Finland by developing a national recommendations for patient-related radiation-protection and treatment room design practices, nationally similar radiation-protection instructions for patients and the guidelines for imaging and dosimetry procedures especially for treatment of hyperthyroidism. To find out the current status, we conducted a survey on radiation protection and imaging practices related to I-131 cancer therapy in Finnish nuclear medicine departments.

Results:

The answers to the survey were received from all Finnish 22 nuclear medicine departments operating in public hospitals. The results showed the need for standardization. During the year 2017 the national clinical guideline was prepared for thyroid cancer treatment in Finland. National radiation protection instructions are important part of this guideline.

Recently a working group was established to implement these national recommendations in practice. This group also further develops guidelines for cancer patients' isolation room radiation-protection design and for dosimetry practices in the treatment of hyperthyroid patients.

Discussion and Conclusions:

The nationally harmonized radiation protection practices will improve patient care and decrease the costs of treatment especially when the in-hospital isolation periods will shorten. Also common national radiation-protection instructions decrease the uncertainty among patient, if they compare the publicly available radiation protection instructions between the hospitals or use the services in different hospitals.

S6-P1

40-years of Nordic cooperation

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1 Swedish Radiation Safety Authority
2 Danish Health Authority, Radiation Protection
3 STUK - Radiation and Nuclear Safety Authority in Finland
4 Norwegian Radiation and Nuclear Safety Authority
5 Norwegian University of Science and Technology
6 Icelandic Radiation Safety Authority

Introduction

The five Nordic Radiation Safety Authorities have long experience of cooperation; it started back in the 1960 and is still ongoing. The Nordic Group on Medical Applications (NGMA) was founded in 1978 and since 1983, the group holds annual meetings where current activities in the five countries are discussed, projects coordinated and solutions to common problems sought. During the years, the group has carried out activities, and issued recommendations, publications and statements.

Scope

The scope of the group is focused on radiation protection issues related to medical exposures. The emphasis is on x-ray diagnostics and interventional radiology but radiation therapy and nuclear medicine are also covered. The annual meetings are held alternatingly in the five Nordic countries and the chair is rotated every third year. When possible the group coordinates its activities with the work of the European working group for medical applications within the Heads of European Radiological protection Competent Authorities (HERCA) cooperation. The Group has also initiated statements that Heads of Nordic radiation protection authorities have given on radiation protection in medical use of radiation. Below you will find activities and publication performed by NGMA.

Activities

Inspection workshops

In 2004, the group held its first inspection workshop. The objective was to provide a forum for exchange of information and experience on inspections carried out by the radiation safety authorities in the medical sector (X-ray diagnostic, nuclear medicine and radiation therapy). This should lead to an enhanced understanding of the inspection practices in the Nordic countries providing opportunity for improvements in respective countries based on these new experiences. The workshop was a success and was followed up in 2007, 2009 2012 and 2015. At the third workshop, the focus was on different systems of legislation, and how this affects the content and practical carrying out of the inspection. In addition, typical findings during inspections have been addressed.

Inspector exchange

The group decided at a meeting in September 2012 to start an exchange of inspectors between the countries as a part of the education of inspectors. The purpose also was to exchange experience between the different countries and identify good practices on how to inspect. So far eight visits have been performed:

2013 NRPA visit to SSM, X-ray diagnosis
2013 STUK visits to SIS, Nuclear medicine
2013 SSM visit to STUK, X-ray diagnosis
2015 December, SIS visit to NRPA, X-ray diagnostics
2016 September, GR visit to SIS, Nuclear medicine
2017 September, NRPA visit to SIS, Proton therapy
2017 October, SIS visit to SSM, Proton therapy
2018 October NRPA visit to SSM, X-ray diagnostics
2018 SSM visit to SIS, Proton therapy

Joint inspections

Most of the equipment used in medical exposers are sold and maintained by multinational companies. These companies usually have their head quarter, for the Nordic market, in one of the countries. In order to improve the efficiency of inspections for the authorities as well as for the companies, joint inspections have been performed. In 2016 Varian Medical Systems Scandinavia A/S was inspected by the authorities in Denmark and Sweden. Moreover, in 2018 Elekta was inspected by the authorities in Denmark, Finland, Norway and Sweden.

Projects

Quite a few projects have been accomplished resulting in different papers and statements. A current project is Nordic DRL in pediatric radiology, aimed at establishing diagnostic reference levels for x-ray examinations of children, preferably as weight based diagnostic reference curves.

Statements

Title and ingress is shown for each statement below. At our website, http://nordicxray.gr.is/ , you will find the full text.

Statement concerning the increased use of competed tomography in the Nordic countries

The Nordic radiation protection authorities are concerned about the increased use of computed tomography (CT). They want to draw attention to the potential risks involved and avert unjustified CT examinations by implementing the “triple A” concept: Awareness, Appropriateness and Audit. The Nordic authorities have agreed to issue this joint statement directed to the professional societies and health authorities, notwithstanding the distinct recognition of the large benefits of CT as a diagnostic tool.

Statement on Bismuth shielding of patients in CT examinations

Bismuth shields have the potential to reduce dose to anterior organs in patients during CT scanning, if used properly. Unfortunately, there are several disadvantages associated with the use of bismuth shields, especially when used with automatic exposure control or tube current modulation. Other techniques exist that can provide the same level of anterior dose reduction at equivalent or superior image quality that do not have these disadvantages. The Nordic radiation protection authorities therefore do not recommend the use of bismuth shielding in CT scanning on a regular basis. The use of bismuth shielding should only be considered if the behavior of the CT-scanner is fully known. In those situations where the behavior of the CT-scanners is not fully known, we recommend that alternatives to bismuth shielding should be carefully considered and implemented when possible.

Nordic position statement on justification of new types of practices involving medical exposure

The new European directive on radiation protection reinforces the requirements for justification of medical exposures. The Nordic radiation protection authorities recommend the integration of level 2 justification into established methods for assessments of new health technologies as one approach to strengthen the justification process. A Nordic cooperation has been established between the national radiation protection authorities within the NGMA to support and harmonize the national implementation of this recommendation and to strengthen the dialogue with other relevant national bodies, preferably competent health technology assessment (HTA) bodies.

Nordic guidelines for dose reduction to radiosensitive organs of the patient in conventional radiography and fluoroscopy

These Nordic guidelines are written to emphasize the value of appropriate technique for patient radiation dose reduction in conventional radiology and fluoroscopy. Given that all examinations have been properly justified, and image receptor exposure is optimized based on evaluation of image quality, the guidelines should be considered in order to reduce radiation doses to radiosensitive organs.

Publications

The group has made several publications over the years. Some have been presented in international fora and refereed journals, while others have been published by the Nordic authorities themselves. A list of the publications with titles and in some cases a short description is provided below.

Nordic recommendation on protection of the embryo and foetus in X-ray diagnostics 1989

The recommendations is a follow-up of ICRP decisions at meetings 1983 in Washington, where the validity of the so-called “Ten-Day Rule” was discussed. The recommendations was adopted by the five Nordic countries in 1988.

Report on Nordic radiation protection co-operation

1994 No. 1 Mammography.

The recommendations describe the major assumptions for an optimized mammography system from a technical viewpoint and give advice on how optimization may be achieved.

1994 No. 2 Shielding of Gonads

In addition to radiation protection purposes, the intention behind this recommendation is to achieve a common set of routines in x-ray diagnostic work in the Nordic countries.

1994 No. 3 Quality control and inspection of equipment for medical X-ray diagnostic (in Danish)

1995 No. 4 Glandular tissue dose in film-screen mammography

The report gives the glandular dose conversion factors for various x-ray spectra and breast models.

1996 No. 5 Nordic guidance levels for patient doses in diagnostic radiology

Guidance levels are given for six common conventional examinations performed in radiological departments involving both radiography and fluoroscopy.

1996 No. 6 Radiographic education in the Nordic countries – Content of science and radiation proctetion (in Norwegian)

1999 No. 7 A quality control programme for radiodiagnostic equipment: Acceptance tests.

The aim of a quality assurance programme is to assist a radiodiagnostic facility in consistently obtaining adequate radiological information with a minimum of dose and a minimum of cost.

Papers and presentations

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Conclusions

The five Nordic Radiation Safety Authorities have a long tradition of trust-based co-operation. During decades, the co-operation has provided added value for the authorities and for radiation protection, generated synergies, and shared experiences. It has improved the efficiency of inspections and strengthen our statements in different issues.

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S6-P2

Pediatric CT examinations in Iceland: Frequency and Age Distribution

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Abstract

The increased use of CT in diagnostics, in addition to the higher radiosensitivity of children compared to adults, stresses the importance of monitoring the frequency of pediatric examinations in order to, for instance, evaluate the need for specialized pediatric protocols.

The aim of this work was to study the frequency and age distribution of pediatric (<18y) CT examinations in Iceland during a one year time period from 2016 to 2017. Data were collected from all ten sites in Iceland performing CT examinations; Landspitali University Hospital (LUH) which encompasses the Children's hospital, seven regional hospitals (located outside the capital area) and two private clinics in Reykjavík, performing about 46%, 29% and 25% of all pediatric CT examinations, respectively.

The proportion of pediatric CT ranged from 1.8 to 4.8% of all CT examinations per site. The highest proportion was in a private clinic but the highest number of pediatric examinations performed was at LUH. The total number of pediatric examinations ranged from 6 to 815 per site in the given year; four sites performed >200 pediatric examinations and others performed less than 100/year. The age distribution differed between sites; the most uniform distribution was at LUH while the other sites generally examined older children more frequently. Three sites examined infants (<1y), of which 79% were examined at LUH. The results showed that pediatric CT examinations were performed at every site and the frequency of examinations outside LUH was higher than expected which underlines the need for pediatric protocols at all CT sites.

Introduction

The increased use of computed tomography (CT) in the last decades has raised concerns about the radiation exposure of patients examined, especially of the pediatric population [1]. The radiation dose to the patients can vary considerably for the same examination type. There has for instance been reported a more than 10-fold variation in the estimated median effective dose for a baby within trauma center facilities [2].

Technical improvements in the field of dose reduction have emerged in the recent years and the number of scanning and reconstruction parameters that need to be optimized have increased. A high level of competence in CT imaging techniques is necessary for the optimization of image quality and radiation dose for each examination, especially for pediatric patients [3].

A former Icelandic study concluded that the majority of CT scanners, at sites performing few examinations (less than 5000/year), had very few and even no predetermined pediatric protocols [4]. The operators often argued that pediatric CT examinations were never performed at these sites and thus pediatric protocols were not needed since children were generally sent to Landspitali University Hospital (LUH), which encompasses the only dedicated pediatric hospital in Iceland. This has raised the questions whether there really are no pediatric examinations

performed at small CT sites in Iceland and whether all pediatric CT examinations in Iceland are performed at LUH only.

Purpose

The aim of this study was to investigate the frequency and age distribution of pediatric CT examinations at all CT sites in Iceland to evaluate the need for pediatric CT protocols, especially at small sites.

Methods

All examinations of patients under the age of 18 were considered as pediatric examinations. The pediatric CT examinations performed during a one year time period from 2016 to 2017 were studied and data from all ten sites performing CT scans in Iceland were included. Three sites were located in Reykjavík, LUH and two private clinics (PC1 and PC2); all other sites were small hospitals, of which three were within 100 km from Reykjavík in the south-west part of Iceland (SW1, SW2 and SW3) and four in more remote areas in the west, north, east and south part of Iceland (W, N, E and S). Data from some of the sites was already available at the Icelandic radiation safety authority from a previous data acquisition. An enquiry was sent to the remaining sites requesting the frequency and age distribution of pediatric examinations as well as the total number of all examinations performed during the one year time period studied. The data was generally collected from RIS and/or PACS systems.

For each site, the age distribution and the proportion of pediatric examinations of all CT examinations performed, were analyzed. The pediatric patients were binned into eighteen age intervals: $0 \leq \text{age} < 1$, $1 \leq \text{age} < 2$ etc., up to $17 \leq \text{age} < 18$. The children examined were also divided into two groups, those younger than the age of nine and those from 9 years old and up to 18. The groups were called the younger and older age group, respectively.

Results and discussion

The total number of pediatric CT examinations was 1768 and ranged from 6 to 815 per site in the given year; four sites performed >200 examinations and others performed less than 100/year. The highest number of pediatric examinations were performed at LUH, where 46% of all pediatric CT examinations were performed. The proportion of pediatric CT of all CT examinations ranged from 1.8 to 4.8% per site; the highest proportion was in a private clinic and the lowest in one of the small hospitals. The data from site W, where pediatric examinations were <10, was not analyzed further.

The age distribution of all pediatric CT examinations in the given year is shown in Fig. 1. The frequency generally increases with age, with the exception of infants (<1 y/o).

The age distribution at each individual site is demonstrated in Fig. 2, where the first bar represents a uniform age distribution. The age intervals are represented with the shade of the color; the column becomes brighter as the children examined get older. According to Fig. 2, the site with the most

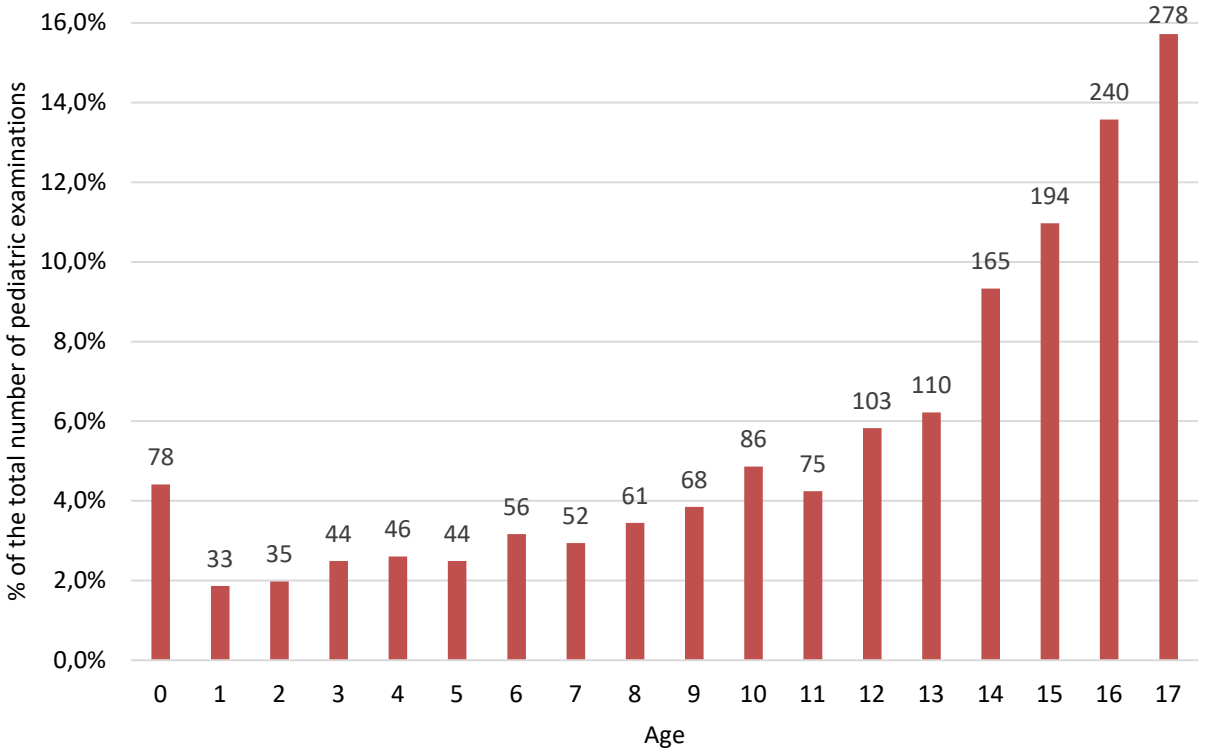

Fig. 1. The age distribution of the total number of pediatric CT examinations (top of each bar) and the proportion of the total number of pediatric examinations, from all ten CT sites in Iceland, during a one year time period in 2016 - 2017.

uniform age distribution was LUH. The other sites generally examined older children more frequently than the younger ones.

The results show a general increase in the number of pediatric examination with age, except for children < 1 year old where the number of examinations is higher than all individual age intervals below 10 years. Out of all pediatric CT examinations, 40% of the children were in the three oldest age intervals (from 15 to < 18). In the past, only children up to 15 years old have been included in the study of pediatric CT [5] but here children up to 18 years old were included.

The percentage of examinations performed on children under 9 years old, of all pediatric examinations performed at each site, is shown in Table 1 and compared to the percentage of children that are 9 years old and older. Out of all the children examined at LUH, 36% were < 9 years old and 64% were ≥ 9. Two of the other sites examined no children younger than 9 years old during the year studied. In the six remaining sites the proportion of pediatric examinations of children younger than 9 years old ranged from 4% to 22% of all pediatric examinations at each site.

Table 1. The percentage of children examined at each site in the younger (up to 9 years old) and older (9 years old and up to 18 years old) age groups.

	LUH	PC1	PC2	SW1	SW2	SW3	W	N	E	S
0 to < 9 y/o	36%	21%	4%	0%	8%	0%	*	22%	19%	6%
9 to < 18 y/o	64%	79%	96%	100%	92%	100%	*	78%	81%	94%
	100%	100%	100%	100%	100%	100%	*	100%	100%	100%

* Data not included because less than 10 examinations were performed.

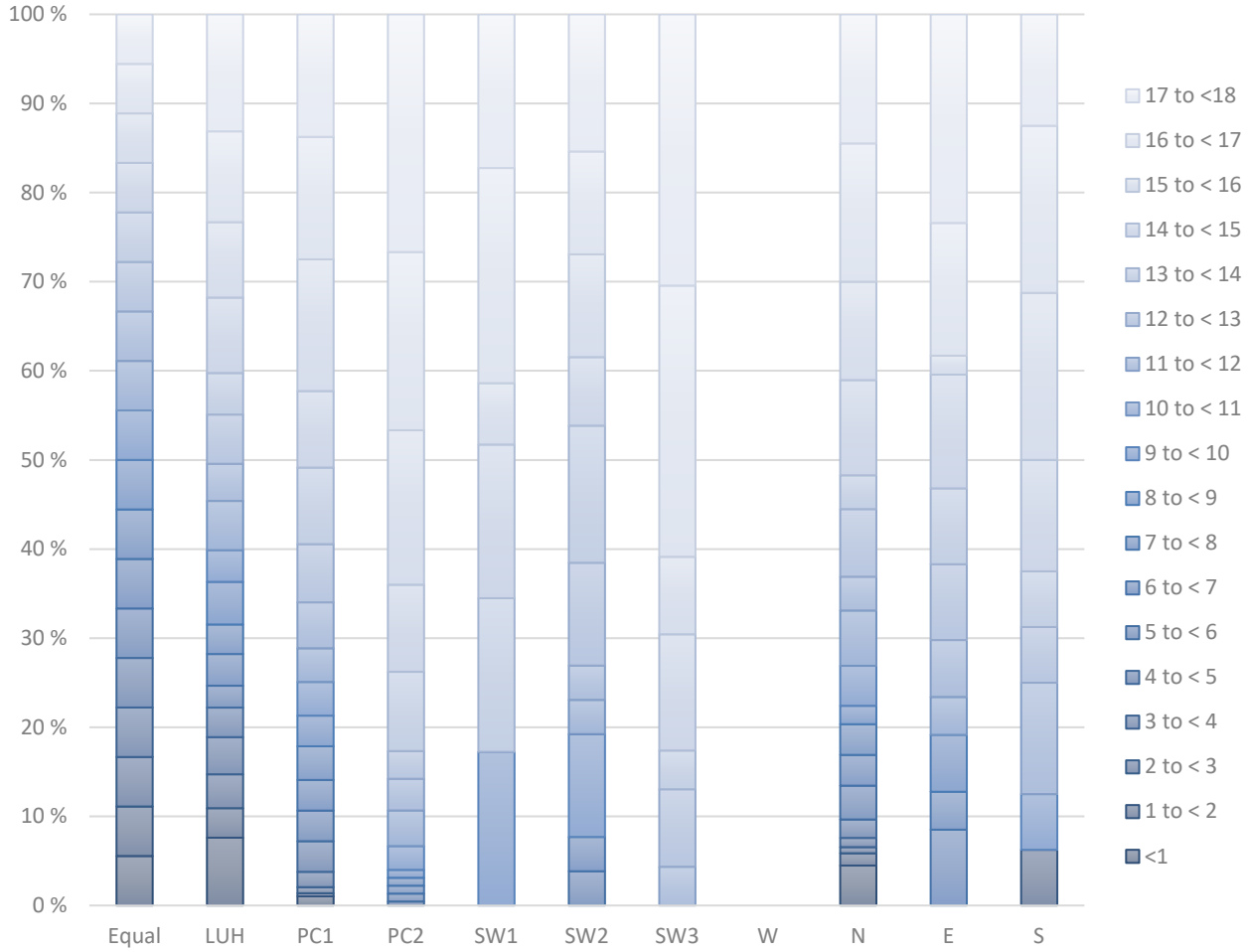

Fig.2. The age distribution of pediatric CT examinations at each site. The column to the far left shows a uniform/equal age distribution and the color shading represents different patient age intervals. For one hospital (W) the pediatric examinations were too few to be represented here. See Methods for description of site abbreviations.

In total, 66% of all pediatric CT examinations of children under nine years old were performed at LUH but only 39% of children 9 years old and older. A total of 78 infants were examined at three sites, of which 79% examinations where performed at LUH.

The frequency of pediatric examinations outside LUH was higher than expected, given the common notion that children are generally examined at the university hospital (LUH). At two sites, there were no examinations of children younger than 9 years old performed. This might be because both these sites are located within 100 km of LUH which makes it easier for them to redirect pediatric patients to LUH, compared to the more remote sites. Also, in the case of serious accidents in the area patients are more likely to be transferred directly to LUH instead of the smaller hospitals.

This study showed that pediatric CT examinations are indeed performed at small sites and that not all children are sent to LUH for a CT scan. The majority of children in the younger age group (< 9 years old) are examined at the LUH but 61% of examinations of children in the older age group (≥ 9 years old) are performed outside LUH. A possible explanation for why small sites claim not to perform pediatric CT examinations is that older children and teenagers might not be considered as pediatric. For further studies of pediatric CT examinations in small sites, the time period considered should be extended for a better analysis due to the low number of examinations.

At sites where the total number of CT examinations is low, pediatric examinations are extremely rare; in this study there was a minimum of six pediatric examinations performed at one site during the one year time period studied. Predetermined protocols might be of even more importance for rare examinations, than standard ones, due to the lack of operator experience in choosing suitable imaging parameters. That, in turn, makes it challenging to establish good protocols for the examinations in question.

In dedicated pediatric protocols, all parameters are optimized; e.g. tube current, tube voltage, field of view and bow tie filter, playing a key role in the CT dose reduction [6,7]. It is recommended to use pediatric reference protocols, provided by manufacturers, rather than selecting adult reference protocols and adjusting those parameters [8]. The results of this study emphasizes that all CT cites, independent of size, should expect to perform pediatric examinations every now and then and should thus be prepared with preset and optimized pediatric protocols.

Conclusions

Pediatric CT examinations were performed at every site and the frequency of examinations outside LUH was higher than expected, which underlines the need for pediatric protocols at all CT sites.

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S6-P3

Assessment of dose – area product of common radiographic examinations in selected southern Nigerian hospitals

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Over the years, radiographic examinations is the most used diagnostic tools in Nigerian health care system but most diagnostic examinations carried out do not have records of patient doses. Lack of adequate information on patient doses has been a major hindrance in quantifying the radiological risk associated with radiographic examinations. This study aimed at estimating dose – area product (DAP) of patient examined in X – ray units in selected hospitals in Southern Nigeria. The standard projections selected are Chest Posterior-Anterior (PA), Abdomen Anterior-Posterior (AP), Pelvis AP, Pelvis Lateral (LAT), Skull AP/PA, Skull LAT, Lumbar Spine AP, Lumbar Spine, LAT. Measurement of entrance surface dose (ESD) was carried out using thermoluminescent dosimeter (TLD). Measured ESDs were converted into DAP using the beam area of patients. The results show that the mean DAP ranged from 0.17 to 18.35 Gycm2. The results obtained in this study when compared with those of NRPB-HPE were found to be higher. These are an indication of non optimization of operational conditions.

Keywords: Dose – area product, Radiographic examinations, Patient doses, optimization.

S6-P4

On Conceptus Doses in Cardiology in Finland – A Simulation Report on a CRT Implantation

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Pregnant patients pose a significant challenge in all use of radiation in medicine. Even if conceptus dose is below 100 mGy, cancer risk is estimated to increase similarly to ex-utero babies. In cardiological procedures, pregnant patients are very rare. In our research, we simulated implantation of a cardiac resynchronization therapy device following an actual procedure with the following methods: radio-photoluminescence dosimetry and Monte Carlo calculations based on the actual procedure and a typical CRT implantation. Information on the procedures included use of projections, use of cine, use of fluoroscopy and use of shielding. In my presentation, I wish to discuss the used methodology and obtained results, including harm to the conceptus and effect of shielding and careful planning of the procedure.

S6-P5

Whole body counting for staff monitoring in radionuclide therapy with Th-227

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Background

Th-227 is promising for alpha-therapy, decaying (T½=18.7d) through Ra-223 (T½=11.43d) to stable Pb-207 in 7 steps (5 alpha, 2 beta). Multiple X-rays/gammas allow external detection. Dose coefficients for (Th-227/Ra-223) are high: (7.8/6.9) mSv/kBq for inhalation; ED= 1mSv reached by inhalation of <130 Bq.

Methods

This is detectable in our low-background NaI-based WBC. We measure (1800 s) in two windows. S_1 [K-40 peak] and S_2 [20-450keV]. Signal from (a contaminated) person is modeled:
$S_1 = B_1*(1+b_1) + d * (S_2 – B_2*(1+b_2)) + C$, where
$B_{1,2}$: chamber background. $b_{1,2}$: perturbation by "clean" person (linear functions of BMI, regression from phantom data). d: downscatter factor (function of BMI) to net-counts from K-40. Here, 18 persons with no history of radionuclide work were included (BMI 20-44). C:contamination
Calibration based on known (fresh) Th-227 sample. Sealed sample of Th-227 was followed over 4 months. Model was applied to staff handling Th-227 (6 persons, 55 times in total).

Results

B_1=17.1 cps; B_2=1.26 cps; b_1 and b_2 induce corrections to B_1 of 5-10% (up) and to B_2 of 1-2% (down). Average K-40 correction was 6 cps. Calibration factor (CF) for uniformly distributed "pure" Th-227 is 80 Bq/cps in 77 kg phantom. There is a paradoxical increase in counts for the first 13 days. CF for closed system decreases from 80 Bq/cps (t=0) asymptotically towards 13 Bq/cps.
Detection limit for same-day paired measurements is 50 Bq.
No Th-227 was detected in the 6 persons, mean/std (-10±24) Bq.

Conclusion

Detection limit with WBC is sufficient to document compliance with dose limits.

S6-P6

New Danish Guideline for Quality Control of Diagnostic Monitors

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Introduction

Quality control of x-ray equipment together with all accessories plays a key role in fulfilling the ALARA principle within the medical field. The world of yesterday with film systems and light boxes had very well established tests of these systems, with requirements being an integral part of the Danish legislation up to implementation of the new EU BSS.

Image detection systems at Danish hospitals have for a long time been digital, while the some chiropractic, dental and veterinary clinics still use film systems. However, until 2018 the existing guidance on tests was based upon requirements to film based systems. Therefore, the old parameters such as contrast and artefacts lacked descriptions according to new circumstances. In addition, new aspects and possibilities had not been described at all; such as loss of information by digital transfer and the possibility of establishing remote workstations. This was in contrast to the previous situation where the film was the data media itself and it was described on light boxes at the radiology department.

Method

A working group aimed at establishing national guidelines for diagnostic monitors used in radiology departments was initiated by the Danish Health Authority, Radiation Protection in October 2014. Ten persons from different stakeholders joined the working group, including medical physicists, technicians and representatives from medical device companies. Based on available international standards and national guidelines as well as the participants own experience and knowledge guidelines on acceptability criteria, test methods and time intervals between tests have been established. Focus on establishing time intervals between tests was key, since many of the standards omits this parameter.

Outcome

The Danish Health Authority, Radiation Protection published the new guideline [1] in June 2018 together with a spreadsheet to support measurements [2].

The guideline covers monitors used for diagnosis or other decision with consequence regarding further treatment. Monitors have been divided in three classes:

- Mammography
- Conventional x-ray; including chiropractic and extra oral dental uses
- Other diagnostics; e.g. intervention, CT, intra oral dental

First of all, the guideline contains some general recommendations for different classes of monitors, shown in Table 1.

Table 1. Recommended specifications

Class: / Parameter:	Mammography	Conventional	Other
Resolution [1]	**Recommendation:** 5 Mp	According to diagnostic needs **Recommendation:** 3 Mp	According to diagnostic needs **Recommendation:** 2 Mp
Set calibrated luminance, L_{max} [cd/m^2]	**Recommendation:** 450	**Recommendation:** 400	**Recommendation:** 400
Number of grey levels in monitor and graphics card (bit depth) [bits]	**Recommendation:** 10	**Recommendation:** 10	**Recommendation:** 10
Built-in LUT	Yes	Yes	Yes
Interface (cable and graphics card)	According to diagnostic needs	According to diagnostic needs	According to diagnostic needs

[1] 'According to diagnostic needs' means that the image should be viewable in full resolution, while the recommendation gives the opinion of the working group on what is the typical resolution needed at the time of the publication of the guidelines.

Furthermore, the guideline describes in detail how quality control of the monitors can be carried out through the following tests:

- Ambient viewing conditions
- Contrast ratio
- Contrast response (Grayscale Standard Display Function, GSDF)
- Luminance, including difference between monitors
- Homogeneity
- Artefacts
- Visual test

For each of the tests, suggested tolerances are stated. All of the tests are recommended to be carried part of the acceptance test of the monitor. The guideline also recommends tests to be repeated – as part of performance and/or constancy tests as well as after repair. For test that should be repeated regularly, recommendations on time intervals are set up.

Table 2 shows a more detailed list of the tests together with recommended tolerances and intervals between tests.

Table 2. Recommended test, including tolerances and test intervals

Test • Tolerance	Test type and interval		
	Acceptance test	**Performance test (yearly)**	**Constancy test**
Ambient viewing conditions • **All modalities** $L_{min} \geq 1{,}5 \cdot L_{amb}$ **Recommended ambient level:** • **Mammography** **< 10 lx** • **Conventional and other** **< 50 lx**	x	x	
Contrast ratio, L'_{max}/L'_{min} • **All modalities** **≥ 250**	x	x	
Contrast response (GSDF), deviation • **Mammography and conventional** **< ± 15 %** • **Other** **< ± 20 %**	x	x	
Luminance, L_{max} **1. Deviation from desired** • **All modalities** **< ± 10 %** **2. Deviation between different monitors in the same setting** • **All modalities** **< ± 10 %**	x	x	
Homogeneity • **All modalities**	x Deviation < ± 15 %	x No visible inhomogeneity	
Artefacts • **All modalities** **No significance for diagnosis**	x	x	
Visual test • **All modalities** **Evaluation OK**	x	x	Quarterly
Cleaning • **All modalities** **Carried out**			At least before each test. Recommendation: weekly
Information from Table 1 • **All modalities**	Included as part of test report		

Acknowledgements

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S6-P7

HERCA activities relating to medical applications

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HERCA was founded in 2007 on the initiative of the French Autorité de sûreté nucléaire (ASN). It is a voluntary association in which the Heads of Radiation Protection Authorities work together in order to identify common interests in significant regulatory issues and propose practical solutions for these issues. HERCA works on topics generally covered by provisions of the EURATOM Treaty. The goal of HERCA is to contribute to a high level of radiological protection throughout Europe. The uniqueness of HERCA, as compared to other existing networks in radiation protection, is that it is composed of the Heads of the Authorities, people who either have decision-making capacity or can at least have a major influence on policy and decisions within their country.
The HERCA Working Group on Medical Applications (WG MA) covers all radiation protection issues concerning medical applications of ionising radiation for diagnosis and therapy.
The working group organises its activities through Working Packages (WP). The topics of the current WPs are Inspection competences, Equipment, Awareness in Medical exposure and Clinical audit. In previous years HERCA undertook actions on the topics of Justification, Stakeholder involvement with CT manufacturers, Generic justification and Accidental and Unintended Exposures. For these topics a number of HERCA position papers were published and can be found on the HERCA website. With respect to the publication of Council Directive 2013/59/Euratom, the WG MA has and is paying particular consideration to the transposition and implementation of this new Basic Safety Standards Directive.

S7-O1

Cores – Consortium for Radiation Safety Research

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Abstract

While there has been long-standing cooperation between STUK and universities, such ties were further strengthened and formalised after the government comprehensive reform of the Finnish research and innovation system in 2013. This led to the setting up of the national Consortium for Radiation Safety Research (Cores) and the formulation of a national programme on radiation safety research in Finland. Currently, Cores members include STUK, Aalto University, the University of Turku, Tampere University (as of 1.1.2019, the University of Tampere and Tampere University of Technology merged), the University of Helsinki, the University of Eastern Finland, the University of Jyväskylä, the University of Oulu, Lappeenranta University of Technology, Åbo Akademi and Technology Research Centre VTT Oy.

Introduction

This paper provides information on the national radiation safety research programme of Finland and the activities of the Consortium for Radiation Safety Research (Cores). The Agreement to set up Cores was signed between STUK and nine universities in 2015 [1].

Radiation safety research activities of Cores members 2018-2022

The updated national radiation safety research programme provides more detailed information on the research activities of Cores partners as well as the five university hospitals [2]. The main lines of research of Cores partners are summarized below.

STUK – Radiation and Nuclear Safety Authority

The main areas of research in STUK include medical use of radiation, non-ionising radiation, radiation in the environment, measurement of radiation, emergency management and nuclear security arrangements and, health effects of radiation. The European Union radiation research programs are currently carried out mainly in consortia and calls organized by large research platforms. Participation in the planning of research programmes and calls is important as it provides an opportunity to have impact in the priorities. STUK participates in the Working Groups on Strategic Research Agendas of NERIS, ALLIANCE, EURADOS and MELODI platforms. STUK also participates in the strategic working group of the metrology research programme (EMPIR).

In STUK strategy for years 2018-2022, effective national radiation safety programme is taken up as one of the main targets. Radiation safety research generates experts, tools and knowledge for authority supervision and emergency preparedness. Via the co-operation with universities and the TULANET network, STUK aims to set radiation safety research as one of the key areas for the universities and research centers and to make sure that STUK is a central part of national and international networks carrying out research that is relevant for STUK. The networks with universities and research centers are advanced via exchange of researchers, supervision of theses,

collaborative projects and joint symposia. Funding for research is acquired, for example, by allocation of income from expert services. STUK also plans influencing research funding agencies and ministries to ensure sustainable funding for radiation safety research and participation in national and international projects.

Aalto University

Research related to radiation safety at Aalto University is focused around two main themes: materials for radiation detectors (applied physics, materials science, electrical engineering) and detection technologies (applied physics, applied mathematics, computer science, electrical engineering). Novel semiconductor materials for photodetectors, with wavelengths ranging from infrared through visible to ultraviolet (hence extending to ionizing radiation) are developed in several projects. Novel materials are explored and new detector concepts developed also for neutron detection. The detector concepts rely on innovative approaches and neutron-sensitive isotopes directly integrated into the semiconductor matrix, allowing for simple, robust and autonomous operation designs. Gamma-ray detection technologies are developed both for radioactive materials analysis and medical imaging applications such as positron emission tomography or spectral computer tomography. The research is focused on detector systems, data acquisition and signal analysis. Detection systems for non-ionizing radiation – magnetic fields and THz signals (mm-waves) – are also developed.

University of Turku

Research relevant for radiation safety is carried out in connection of geology, space research, and nuclear medicine at Turku University Hospital and Turku PET Centre. Recent research has focused at studying the brittle bedrock structures, particularly with respect to the older bedrock structures and the heterogeneous (palaeo)stress field of the crust. The investigations have significant application potential within nuclear waste disposal projects. Cosmic radiation, solar energetic particles and radiation belts consisting of charged particles are trapped in the Earth's magnetic field. Space radiation adds to the radiation dose of the flying personnel. Radiation safety research at the Hospital District of Southwestern Finland (VSSHP) is done mainly at Turku University Hospital, focusing on patient safety, dosimetry of both patients and personnel and development of new methods and instrumentation. VSSHP works together with University of Turku and Åbo Akademi where the biggest joint venture is the National PET Centre. The number of medical imaging studies is rapidly increasing and more complex imaging methods are widely available. Imaging has become routine also during surgery in operating rooms. In nuclear medicine with multimodality devices such as PET/CT and SPET/CT optimization is vital and low dose CT often preferable. Working with open sources makes it important to reduce finger doses to the staff.

Tampere University

The University of Tampere and Tampere University of Technology were merged at the beginning of 2019, creating the second largest university in Finland. The new community adopted the name of Tampere University.

Research related to radiation protection conducted at University of Tampere focuses on radiation dose assessment and health risks from radiation. Dosimetry research has focused on doses to off-target tissue in radiotherapy. Long-term health effects of radioiodine therapy has been a focus area, with several studies evaluating risks of subsequent neoplasms, other diseases and mortality. In addition, cardiac effects of radiotherapy for left-sided breast cancer have been evaluated.

Dosimetry from radiotherapy for breast cancer has been a central theme. Extensive research has been carried out in radiation epidemiology. Risk of cancer, as well as non-cancer diseases has been evaluated among subjects exposed occupationally, from environmental sources or through medical uses of radiation. Health outcomes have included childhood cancers, lens opacities and pregnancy outcomes. Late sequelae of radiotherapy are a current focus, as well as cancer risk from computerized tomography in children. The comprehensive Finnish population and health care registers have been utilized for conducting large-scale studies. Wide international networks of collaboration have been established and several studies conducted as European projects, as well as with WHO and IARC. In the field of non-ionising radiation, a central theme is the effects of UV radiation on skin and indirect effects on the physiology. Health effects of radiofrequency electromagnetic fields from mobile phones are being evaluated in an international cohort study (COSMOS), with outcomes ranging from symptoms to cancer and neurodegenerative diseases.

The technological research in the new Tampere University has three main areas: novel optics and photonics methods for radiation detection, corrosion studies on the copper capsules used for final disposal of spent nuclear fuel, and biosphere modeling. Development of novel radiation detection methods making use of optics and photonics is a promising methods for localization and cleaning of alpha contamination. Physicochemical phenomena on material surfaces have focused on corrosion studies on the copper capsules used for final disposal of spent nuclear fuel. The spent nuclear fuel generated by Finnish nuclear power plants is stored underground in capsules, where the innermost part is made of copper. The corrosion resistance of the capsules over the millennia is one of the most critical properties of the capsules. Modeling of radionuclide transport in the biosphere has been addressed in connection of spent fuel management. The transport of radionuclides in the biosphere is usually modeled with the so-called compartment model, where the biosphere is described in compartments (such as lake, plants, etc.), and the transport between compartments is described using concentration ratios (CR). The behavior of radionuclides inside the compartment is described by distribution coefficients (Kd). Sensitivity analysis can be used to obtain information on which kinds of input parameters have the greatest effect in terms of the radiation dose ending up in humans and, which kinds of ecosystems are the most critical.

University of Helsinki

University of Helsinki addresses a wide range of research on radiation and nuclear safety. The main units contributing to this field are the Radiochemistry laboratory of the of Department of Chemistry, the medical physics team of the Department of Physics (jointly with HUS, the Hospital District of Helsinki and Uusimaa) and the accelerator laboratory, and Helsinki Institute of Physics. The Radiochemistry unit has studied environmental radioactivity for more than fifty years. Behavior of natural radionuclides and those from the fallouts of the atmospheric nuclear weapons tests and the Chernobyl accident has been studied in the environment and food chains. At the moment the Radiochemistry unit is focusing on transuranium elements in food chains, on natural radionuclides in mining wastes and on the behavior long-lived fission products in biosphere. Medical Physics in clinical and preclinical research has several applications. Molecular radiotherapy (MRT) applies multiple cell-level mechanisms (e.g. receptor binding) to deliver lethal radiation doses selectively to malignant cells. Optimization in diagnostic radiology involves a carefully set balance between diagnostically reliable image quality and coverage in connection with lowest applicable radiation exposure.

Radiation metrology has several applications. Accurate and reliable radiation measurements are a cornerstone of medical applications that use ionizing radiation. In particular in external beam radiotherapy, technical advances in treatment equipment have led to a situation where the traditional measurement methods are no longer capable of providing reliable and accurate dose information. Radiation measurements are essential in all safety, security and safeguards (3S) domains of radiation protection authorities. Fundamental studies of radiation effects in materials are carried out as part of the international collaboration networks associated with the big science facilities ITER, CERN and FAIR. A particular focus area is damage in nuclear reactor materials.

University of Eastern Finland

The main lines of radiation safety research at the University of Eastern Finland include biological and health effects of non-ionising and ionizing radiation, radioecology and research at the Kuopio University Hospital on the medical use of radiation (radiotherapy, radiology, nuclear medicine).

Research on extremely low frequency magnetic fields (ELF MFs) focus on biological studies aiming at understanding the mechanistic basis of the reported health effects of ELF MFs, such as childhood leukaemia, adverse reproductive outcomes and Alzheimer's disease. The registry of residential buildings with indoor transformer stations is an excellent basis for high-quality epidemiological studies on health risks of ELF MFs. Human exposure to intermediate frequency (IF) fields is increasing due to new technologies, but possible health effects are less well known. Experimental and epidemiological studies are conducted on cancer-related, reproductive, developmental and behavioural/cognitive effects. As for radiofrequency (RF) electromagnetic fields, the focus is on nervous system effects. The increasing use of magnetic resonance imaging (MRI) has raised discussion on the possible health risks of static magnetic fields.

Research on the effects of ionizing radiation is related to two main areas: risks from low doses that are relevant for radiation protection, and the use of ionising radiation in medicine. In addition to cancer, ionising radiation has been shown to induce other tissue reactions, such as vascular diseases at much lower doses than previously assumed. Another scientific question is individual sensitivity. Currently, neither the individual variation in radiation sensitivity, the functional variations within the patient anatomy nor the radiobiological aspects of treatment are accounted for in the RT treatment planning. In research projects, the radiobiological and biological aspects will be incorporated into the RT planning systems. This will enhance and individualise the RT dose prescriptions and protect the well-functioning areas from radiation injury. This will hypothetically increase tumour control and decrease the normal tissue toxicities resulting from RT.

Radioecological research aims at understanding transfer of radionuclides in ecosystems, as well as assessment of radiation effects on wildlife/ecosystems. UEF research focuses on developing improved radioecological modelling based on adequate theoretical and empirical understanding of the uptake of elements into organisms in Finnish ecosystems.

University of Jyväskylä

The Nuclear Spectroscopy group at JYFL has significant experience and expertise in the use and development of modern radiation detection and data acquisition techniques, along with simulation of detector characteristics and analysis techniques. It is envisaged that this expertise will be exploited to develop improved instrumentation for application of state-of-the-art nuclear spectroscopic techniques to problems in safety, security, safeguards and environmental and

health surveillance. An example such activities is the system to produce, isolate and contain xenon isotopes for the calibration of International Monitoring System run by the Comprehensive Nuclear Test Ban Treaty Organisation (CTBTO) to detect possible clandestine nuclear tests or releases. Another example is the use of gamma-gamma coincidence techniques to better identify activities found in aerosol particulate filters and to reduce the minimum detectable activity in such measurements.

University of Oulu

With the developments taking place in aerial imaging and advancements in battery technologies, UAVs have become cheaper and much more viable in performing large-scale radiological data collection missions. Also, the weight of sensitive radiation detection sensors and other onboard hardware has reduced significantly. Localisation of radiation sources can be performed accurately and safely, at least in outdoor environments. Cheaper and more advanced UAVs mean less expenses for surveying contaminated environments.

Justification and effectiveness of radiological examinations is the major theme for the medical radiation protection research in Oulu University Hospital. The appropriate use of different radiological examinations is important both medically and economically. In particular, justification must always be considered with examinations using ionising radiation due to the possibility of radiation-promoted carcinogenesis. Justification includes consideration of all alternative procedures requiring no exposure to radiation, i.e. it is important to utilise ultrasonography (US) or magnetic resonance imaging (MRI) whenever possible.

Åbo Akademi

Neutrons from proton-induced nuclear reaction constitute a radiation safety problem around medical cyclotrons. During the operation, the surrounding structures are activated by neutrons. The oldest cyclotron at the Turku PET Centre is more than 40 years. The aim is to monitor neutron fluxes, measured neutron-induced activities in surrounding structures, and finally to perform a Monte Carlo simulation to get a better understanding of the processes involved. The long-lived radioactivity will be measured in the preparation of a decommissioning plan.

Technology Research Centre VTT Oy

Serpent is a three-dimensional continuous-energy Monte Carlo transport calculation code, developed at VTT, originally for the purpose of generating input data for reduced-order calculation codes used for nuclear reactor analysis. Serpent has been distributed free of charge for research and educational use by the OECD/NEA Data Bank and RSICC since 2009. The user community has grown to almost 800 users in 200 organizations. The Serpent code is now becoming a practical calculation tool for the radiation safety community.

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S7-O2

Recent Nordic research collaboration results obtained under the NKS-B programme

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The Nordic countries have throughout decades shared a regional research and development program on nuclear reactor safety and emergency preparedness: NKS. Its results have received great recognition and have been integrated in state-of-the-art tools over the world, e.g., for emergency preparedness and response management. The presentation provides information on recent results from the NKS-B programme, which comprises the topics emergency preparedness, radioecology, and measurement technologies and strategies, e.g., also in waste management and decommissioning. Although the Fukushima accident did not lead to any radiological consequences in the Nordic region, it taught a number of important lessons of generic nature that can further strengthen and secure future maintenance of the Nordic region's capability to effectively respond to such events, and have since been addressed in NKS activities. Studies of radioecological challenges under NKS-B are by no means restricted to accident scenarios, but also comprise for example aspects of naturally occurring radioactive material (NORM). Among the recent measurement activities in NKS are a series of efforts to secure that Nordic laboratories are able to measure a series of 'difficult-to-measure' radionuclides (including alpha emitters) in for example decommissioning waste, which has become a challenge shared by Denmark, Finland, Norway and Sweden. Over the latest 5 years, a total of 48 topical NKS-B projects have been carried out, comprising organization of 23 exercises, workshops or seminars. All results of these activities are freely available in reports on the NKS website.

S7-O3

Radiation protection research: is Nordic cooperation a way forward to ensure sustainable competence and high-quality research

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Lund university

The definition of radiation protection may be subject for debate and there are perhaps even more opinion on what is actually entailed in the term radiation protection research. Most researcher within fields associated with radiation protection will, however, agree on that there are often grey zones between mandatory radiation protection measures necessary to accommodate with existing regulations, and developments and improvements that are genuinely a novel approach that may be considered as research. The radiation protection research in the Nordic countries is associated with small groups in terms of staff and resources, that often operate in multidisciplinary projects. What are the prerequisites in terms of sheer measurement and technical capacity for enabling viable long-term research? Basic competence may not be considered neither excellent or novel in the contemporary research strategies, but may still be of vital importance for enabling future research. Should these sensitive competences be supported during grants draught, and if so, how should this be done in practice? What are the possibilities to consolidate resources within the framework of Nordic cooperation and what then are the practical ways forward to ensure that such cooperation can attain a sustainable competence in fields such as radioecology, radiochemistry and radiobiology? All these are suggested points to be addressed in a panel discussion on radiation protection research in connection with the NSFS conference.

S7-P1

Neutron dosimetry in Nordic countries

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Introduction

There is a societal need for neutron dosimetry due to radiation sources such as nuclear facilities, stray radiation from accelerators in research and radiotherapy, a new boron-neutron capture therapy station planned for operation in near future in Helsinki and the European Spallation Source in Sweden. Presently, in Nordic countries only STUK has facilities to provide calibrations for the neutron ambient dose(rate). Calibrations for personal dose(rate) is not yet available in Nordic countries. Therefore, dosimetry laboratories from Finland, Sweden, Norway and Iceland organized an experimental workshop with a comparison in neutron calibration fields, as a survey of the neutron dosimetry capability of the laboratories and as a complementary characterization of the STUK facility. The one week workshop was organized in STUK during September 2018. Several neutron and photon-neutron instruments were used to measure neutron fields at STUK premises where neutron fields traceable to Physikalisch-Technische Bundesanstalt (PTB) are available. For neutron calibrations the scattered contribution to the radiation field determines the conformity with the international standards. Both ^{241}AmBe and ^{252}Cf sources were used for measurements of the direct and scattered radiation components. Also, the gamma component of the total dose rate was measured. Due to the dosimetric challenges in mixed photon and neutrons fields, simulations are important in understanding the characteristics of the calibration premises. The neutron energy distribution need to be known since most of the personal dose meters used are of albedo type, i.e. they measure thermal neutrons and the result is a dose due to whole distribution.

Methods

Radiation fields

The radiation fields used were mixed fission neutron and photon fields from two ^{252}Cf (nominal activities 500 MBq and 423 MBq) and an ^{241}Am^{9}Be (185 GBq). The neutron ambient dose-equivalent reference rate at 50 cm and 77.5 cm from source used during the campaign are shown in the Table 1 below. Uncertainties are given as the expanded uncertainty with k=2. Measurements were also performed of the scattered radiation field at distance 77.5 cm with a shadow cone in the primary field.

Table 1. STUK reference values $\dot{H}_n^*$ ±2u in µSv/h

Distance	AmBe	Cf 500MBq	Cf 423MBq
50 cm	660 ± 115	1770 ± 135	25 ± 2
77.5 cm	284 ± 50	775 ± 60	10.9 ± 0.9

The equipment

During the week, 7 different neutron meters were used: Two Berthold LB 6411, three Thermo scientific FH40G-L10 survey meters of which two were equipped FHT 762 Wendi-2 neutron probes and one with FHT 752 Biorem probe and one Canberra Colibri with SN-D probe. In addition, one Sievert instruments were used to measure neutron and γ components of the radiation field. The Sievert instrument is a microdosimetric device developed by SSM [1,2]. The instruments was used with two detectors, a tissue-equivalent proportional counter (TEPC) with 5 mm A-150 wall thickness (SvB), and a detector of identical construction but with a graphite wall (SvC). Both detectors are housed in vacuum containers of 2 mm thick aluminium with diameter 150 mm. The detectors are working at a gas pressure (p) of about 1.4 kPa of propane based tissue-equivalent gas with (volume fractions) 55% C_3H_8, 39.6% CO_2 and 5.4% N_2, to simulate an object size with a mean chord length of about $\bar{l}$=2 µm. The gas density (ρ_0) is 1.798 kg/m^3 at the reference pressure (p_0) 100 kPa and 20 °C [3].

Measurements and simulations

The Californium and americium-beryllium neutron sources were measured as bare sources and with a shadow cone using all instruments. In addition, two strongest sources were measured with lead shielding from 1 to 3 mm with Berthold and Sievert instrument. The shadow cone used is made of polyethylene: 50 cm long and end diameters are 12.5 cm and 25 cm. The measurement distances were 50 and 77.5 cm. The effect of measurement geometry is considered through comparison of measurements and MCNPX calculations. The ambient dose equivalent rates and room return were calculated using MCNPX 2.7.0 code package[4]. The initial neutron energy distributions for ^{252}Cf and ^{241}AmBe sources were taken from ISO 8529-1 standard[5]. MCNPX default libraries were used in the calculations. The sources described in Table 1 were used in the model. The steel and aluminum capsules of the sources were included in the source model as well as the aluminum shelf and steel support structures. Calculations were performed with and without the shadow cone. In addition, the contribution to scattering due to air between the source and detector was studied by calculating the distributions as “air only”, i.e. the model was constructed without walls, floor and ceiling. Simulations were carried out in two source-detector distances, 50 and 77.5 cm. To record results, tallies 2 and 5 were used. Tally 2 is particle flux averaged over a surface and tally 5 is a particle flux at a point detector. Tally 2 was 30*30 cm surface centered in air at the reference distance. Tally 5 were also in air centered at the reference distance. In order to get the dose rate, dose function was used to modify tally 5. The coefficients were taken from ICRP 74[6]. Tally 5 totals for all neutron and uncollided neutron were used to obtain the room return. Energy bins used were from $4\cdot10^{-7}$ to 14 MeV, total of 52 points. The number particle in simulation was set high enough (>10^7) that the statistical uncertainty on tally bins were below 5%. The simulated room return was calculated using the tally 5 totals of all and uncollided neutron distributions.

Results and discussion

The calculated and measured ambient dose equivalent rates are in good agreement, see Table 2. In this table, measurement results are those taken with Berthold LB6411.

Table 2. Measured and simulated ambient dose equivalent rates at the reference distance (77.5 cm).

Source	Measured $\dot{H}^*(10)$ [µSv/h]	Simulated $\dot{H}^*(10)$ [µSv/h]
^{241}AmBe	280 ±40	300±20
^{252}Cf	10.9 ±1	12±1

All instruments give 7-10% room return, good agreement within the measurement uncertainties. There difference between measured and calculated room return results can be explained only partly with energy response of the LB6411 detector used, results are shown in Table 3. Additional calculations without walls, i.e. air only, shows that room return decreases by a factor of almost two compared to "full room". However, there is some materials in the room that are not yet included in the model but are included in the measurements. They may have larger contribution to scattering conditions than estimated earlier. This contribution need to be verified if it is enough to make calculations and measurements consistent.

Table 3. Measured and simulated room scatter values at the reference distance (77.5 cm).

Source	Measured	Simulated	
		full room	no walls
	[%]	[%]	[%]
^{241}AmBe	9	17	10
^{252}Cf	8	16	9

Figure 1 below displays simulated energy distribution for a ^{252}Cf source, calculated as free in air, with shadow cone and with ISO slab phantom. With the shadow cone placed between the source and detector, neutrons cannot enter the point of reference directly. Neutrons reach detector only via (inelastic) scattering from walls and air.

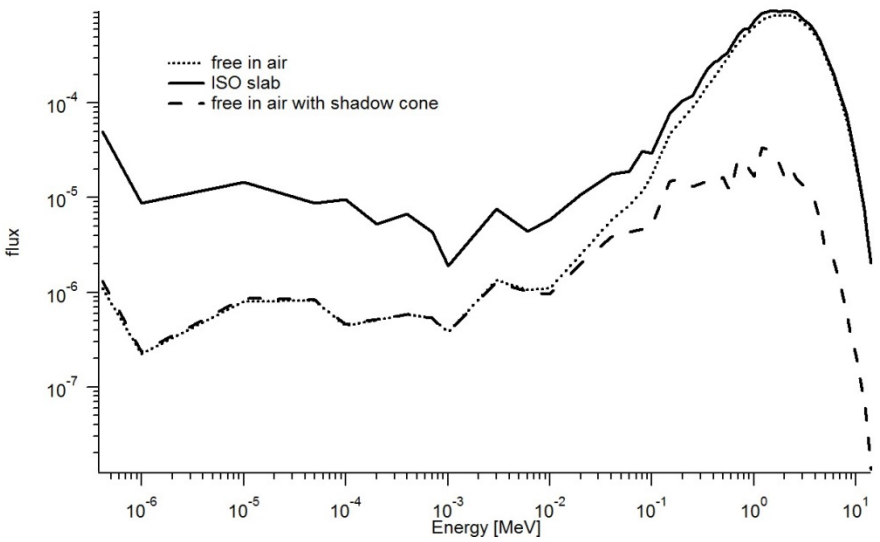

Fig. 1. Simulated neutron distributions.

There were small deviations between calculated and measured room return (the ratio of scattered and direct neutron fields) which will be examined further. The measurement results of the room return with different detectors were in good agreement. In addition, the ratio of the measurement results at 50 cm and 77.5 cm were 42% which exactly according to square law. The Sievert instrument used to measure the photon component of the radiation field. For the Cf field the result is 5% and for AmBe field 25% of the neutron dose rate. Additional measurement with lead shielding decreased the photon contribution significantly, while neutron dose rate were intact. The photon dose rate of AmBe is reduced already with 1 mm lead while californium require 3 mm of lead for significant reduction.

Conclusions

The overall conclusion is that the measurements were successful. The instruments showed a generally good agreement with the reference $H^*(10)$-values, taking into account the calibration coefficients from previous calibrations. The measured photon component were at expected level. The deviation between calculated and measured room return requires attention. As the commonly used personal dosimeters for neutron are of albedo type, scattering contribution need to be well known in the calibration facility. Detailed characterization of the STUK calibration facility will continue, finally allowing calibration for personal dose equivalent.

Acknowledgements

As a corresponding author, I want to emphasize good working spirit among NORDOS group. NORDOS group is formed from Nordic SSDL laboratories who operate in Nordic national radiation protection authorities.

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S7-P2

Actinium in urine

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Radiopharmaceuticals like XOFIGO are routinely produced by the radiopharmacy division at IFE. Due to short half-life of the active component ^{223}Ra (11.43 days) it is produced from the mother nuclide ^{227}Ac. The high radiotoxicity of ^{227}Ac necessitates monitoring of potential intake for employees involved in the production. ^{227}Ac is mainly a beta-emitter with only 1,38 % of the decays are alpha-decays making the direct observation of ^{227}Ac as an alpha-emitter unreliable. The low gamma yields (<0.009 %), in combination with a high radiotoxicity necessitates a more precise detection method than full body counting.

24 h urine samples were collected, acidified, and spiked with ^{229}Th in equilibrium with daughters. Actinides were co-precipitated with phosphate, followed by a separation with cation exchange columns to remove Ca and chromatographic separation with DGA-resin to separate Ac from interfering actinides. The yield was determined from the ^{225}Ac peaks within a few days following the separation to avoid excessive decay of ^{225}Ac and ingrowth of ^{227}Ac-daughters. The targets were then left for approximately 45 days before ^{227}Ac was determined from the signal from ingrown ^{227}Th or combined ^{227}Th / ^{223}Ra peaks. The sample peaks were corrected for residual ^{225}Ac activity either through decay corrected numbers from the yield determination or calculation of the ^{217}At peak (6.97-7.18 MeV).

The method was validated with urine samples spiked with ^{227}Ac and reference material IAEA RGU-1. Results found to well in accordance with added spike values in urine samples and recommended values from the reference material.

S8-O2

Introducing the concept of the isodose for optimization of decontamination activities based on typical Northern European houses

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Introduction and purpose

After the airborne release of radionuclides and their deposition on the ground and other structures the external radiation exposure contributes considerably to the total radiation exposure of the population [1]. However, building structures can reduce this exposure depending on the geometry of the buildings depending on the geometry of the buildings, the distribution of the radiocontaminants, and the residents' occupancy. 90% of the contamination in the topsoil layer can be removed by thorough and consistent removal, provided that the depth is optimized according to the vertical distribution of the contaminants [2], but the costs of equipment, consumables, and skilled personnel can be very high, and the construction of complex waste repositories may also be necessary [3]. Focusing decontamination activities on areas that have the greatest impact on the radiation exposure of the population can therefore minimize resulting waste and costs, taking into account the shielding properties provided by the building structures.

For this purpose, the isodose concept was developed and by applying it as isodose lines for a two-dimensional source area, it illustrates the extent to which specified areas contribute to the external radiation exposure at specified observation points [4]. The concept was applied to two typical Swedish residential houses of different construction materials to determine isodose lines at defined observation points inside the houses and for a combination of those points based on the residents' occupancy. The impact of vertical migration of contaminants in the soil and their variability was studied as well.

Methods

Introducing the concept of the isodose

In case of radioactive contaminants on the ground, on other outdoor surfaces (including soil, roofs, walls, windows, and pavements), vegetation, and in the air (primary contaminant plume or resuspended radioactive matter), buildings structures naturally provide some shielding. A measure of a building's capacity to attenuate external radiation is the so-called shielding factor, which can range between the value of zero (all external radiation is shielded) up to unity (building provides no shielding at all). In Hinrichsen et al. [4] was demonstrated how various materials and the angle of incidence of radiation influence the shielding factor with the conclusion that some contaminated areas have a higher influence on the radiation exposure inside the building than others. Furthermore, also the distance from the contaminated areas to a certain location inside the house (defined in terms of so-called observation points), influences the radiation exposure at an observation point. To further optimize the decontamination measures it is therefore of interest to study which contaminated areas have the highest impact on the radiation exposure indoors leading to the concept of the isodose:

In Hinrichsen et al. [4] an isodose, $ID_{i,k}$, is defined by the outer boundary of one or more zones in space that contribute, for the most part, a given fraction k to the total external dose $D_{i,\infty}$ at the

observation point i. If $\rho_{D,i}(\vec{r})$ is a continuous function of the dose contribution density with a maximum $\rho_{D,i,max} < \infty$, the isodose can be chosen from the range $0 < ID_{i,k} < \rho_{D,i,max}$ and the fraction k_i resulting from the zone or zones determined by the isodose is then given by:

$$k_i = \int f\left(\rho_{D,i}(\vec{r})\right) dV / D_{i,\infty} \quad FOR \; f\left(\rho_{D,i}(\vec{r})\right) = \begin{cases} \rho_{D,i}(\vec{r}), & \rho_{D,i}(\vec{r}) \geq ID_{i,k} \\ 0, & \rho_{D,i}(\vec{r}) < ID_{i,k} \end{cases} \tag{1}$$

The concept can also be applied to more than one observation point [4] to represent various locations in the building, preferably those that are most likely occupied by the residents in a household. By then introducing so-called occupancy factors, p_i, for the various observation points into Equation 1, the isodose fractions, k_i, can be modified to account for the typical occupancy by the residentials within the house according to:

$$k = \int f\left(\rho_D(\vec{r})\right) dV \Big/ \sum_i D_{i,\infty} \cdot p_i \;\; \forall \;\; 1 = \sum_i p_i$$

$$FOR \; f\left(\rho_D(\vec{r})\right) = \begin{cases} \sum_i \rho_{D,i}(\vec{r}) \cdot p_i, & \sum_i \rho_{D,i}(\vec{r}) \cdot p_i \geq ID_k \\ 0, & \sum_i \rho_{D,i}(\vec{r}) \cdot p_i < ID_k \end{cases} \tag{2}$$

Description of the Monte Carlo calculations

The Monte Carlo calculations for typical Swedish house were performed with the transport code MCNP6 [5], using the nuclear cross-section data set ENDF/B-VII.0 [6]. The definition of the geometry of the houses with the most common building materials in Sweden, namely wood and brick, are based on the construction drawings and descriptions of actual Swedish houses made available by the Urban Planning Department of the Municipality of Hässleholm (Stadsbyggnadskontoret, Hässleholms kommun). In this study a total of eleven observation points were defined within these buildings.

Computations were performed for source regions of 1 m x 1 m plane squares in a 1 m x 1 m grid up to a lateral of 10 m from the sides of the houses. Three ground penetrations, at ground level, and 2.5 cm and 5 cm below ground level, were simulated to study the impact of ground penetration. Simulations for infinite horizontal plane sources were performed to obtain reference values. A radioactive source energy of 0.662 MeV was assumed in the calculations as this is the energy of the gamma-rays emitted by the fission product ^{137}Cs, which is the radionuclide of greatest concern in connection with accidental release from nuclear power plants. The detector regions were defined as air-filled spheres with a diameter of 30 cm, positioned 1 m above ground according to the defined observation points.

Results and discussion

Isodose lines around the wooden and the brick house at the eleven observation points were determined for homogeneous ^{137}Cs contamination at ground level, and 2.5 cm and 5 cm below ground level. The results are presented graphically in a report that is soon be published [7]. They show that the shape of the areas encompassed by the isodose lines for a given observation point are relatively similar for all depths of the contamination, and for both the wooden and brick house. The shapes of the isodose lines reflect the different materials, as well as the positions of

doors and windows as they shield less than the walls. The zones for deposited contamination below ground level (2.5 cm and 5 cm, respectively) become smaller since fewer gamma photons from remote areas reach the observation point due to gamma interactions with the soil.

As a second step occupancy factors, p_i, as described in Equation 2 were applied to determine isodose lines that are more representative of the dose to which a resident is exposed inside the house [7]. The occupancy factors were mostly chosen based on data published in the European EXPOLIS project, in which thousands of people in seven European cities (Athens, Basel, Grenoble, Helsinki, Milan, Oxford, and Prague), were studied with respect to their time budgets, and the hours they spent in various microenvironments. Information from other resources like e.g. the OECD or USDA were included, too. The isodose lines in Hinrichsen et al. [7] show the combination of the influence of the time spent in one room in connection with the already named factors. E.g. the determined isodose lines reflect to a larger part the isodose lines determined for the bed room as the largest share of time at home is spent in this part of the house. Furthermore, as the isodose lines surround now more the entire house than one side of it, some effects become more visible. These are the isodose lines for a wooden house are gentler than those for a brick house, as timber provides less shielding, and thus has less impact on the isodose lines and that the corresponding zones for the brick house are larger than those for the wooden. The size of the zone 2.5 cm below ground level is only half of that at ground level. However, at depth of 5 cm the zones appear to increase slightly.

In a third step the obtained values were connected to a vertical transport model of contaminants in soil and the its impact on the isodose lines was studied over different time scales and two different types of soil. It was found that the upper layer of soil dominates as it contributes more to the air kerma free-in-air than the lower soil levels [7]. Over longer timescales the respective zones become smaller as the contaminants migrate deeper into the soil. The speed of this transition depends on the type of soil.

In a last step the impact of the variability in the deposition of contaminants on the ground around the building on the isodose lines was studied. Based on the knowledge from measurements of ^{137}Cs fallout in settlements in Russia and Belarus following the Chernobyl nuclear power plant accident [8] contamination variability scenarios were generated with a random number generator. Isodose lines for those scenarios were determined showing good agreements with those determined for homogeneous contamination based on the Pearson correlation coefficient [7]. The dose reductions by means of decontamination according to isodose lines were compared with the corresponding reduction by decontamination within a fixed distance from the building. It was found that the decontamination according to isodose lines obtained for a homogeneous contamination scenario is always the better option in respect of dose reduction compared to decontamination within a certain distance [7]. This includes the case of unknown contamination variability, in which isodose lines determined for homogeneous contamination are applied.

Conclusions

It could be demonstrated that the isodose concept is useful for comparing the effects of decontaminating different surface areas and of different house constructions. Downward migration of the fallout in the soil, resident occupancy and variability in contamination were also included in the model. More studies are required to further develop this method into a practical

and useful tool for the optimization of countermeasures in cases of radioactive fallout in populated environments.

Acknowledgements

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S8-O3

Upper estimates for effective doses from release of ^{36}Cl activity during plasma cutting of the DR3 reactor tank

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Abstract

The decommissioning of the former Danish research reactor DR3 is well under way. The reactor aluminium tank (RAT) has been cut into pieces in situ in the reactor pit using plasma cutting. In plasma cutting very hot plasma melts its way through the material where the plasma makes contact with the material. During the plasma cutting air coming up from the reactor pit was monitored for gaseous and particulate activity. It was observed that both gaseous and particulate activity was released. Further analysis revealed that besides ^{3}H, ^{36}Cl was released both as gaseous and particulate activity. The gaseous part of the ^{36}Cl activity was able to pass the ventilation filters and be released to the surroundings. From air monitor data, model for air flow and air flow parameters in the ventilation system an upper estimate of activity released to the surroundings was calculated to be 2,7 GBq ± 0,4 GBq. Effective doses from a maximum daily release to representative persons in the surroundings during no-wind and standard wind condition were calculated. Grass samples from the surroundings were also used to calculate an upper estimate for released ^{36}Cl activity albeit with high uncertainty. ^{36}Cl is considered primarily to come from the graphite moderator which was situated just behind the RAT. Based on information from literature the graphite is likely to contain ^{36}Cl as a result of a purification process using hot chlorine gas. Intense heating of graphite during the plasma cutting of the RAT are thought to have released part of this ^{36}Cl.

Introduction

The aluminium reactor tank (RAT) of the former DR3 research reactor was cut into pieces from February to December 2017 and removed. The cutting of the tank was made in situ in the reactor pit and the cutting was remotely controlled from a station on the ground floor in the reactor building. The tank pieces were moved to a container placed in a room (packing room) built above the reactor pit. The reactor pit and the packing room were ventilated by sucking air from the partly enclosed space between the pit and the packing room which connected the two rooms. Air in the packing room and/or the enclosed space was monitored for particulate (iCAM monitor) and gaseous activity (gas monitor normally used to measure ^{3}H gas). Air from the enclosed space was led directly to the chimney after passing particle filters. Fig. 1 shows a schematic cross section of the setup.

The tank was cut by plasma cutting, in which very hot plasma (several thousand degrees Celsius) melts its way through the tank material. A graphite moderator was situated just behind the reactor tank.

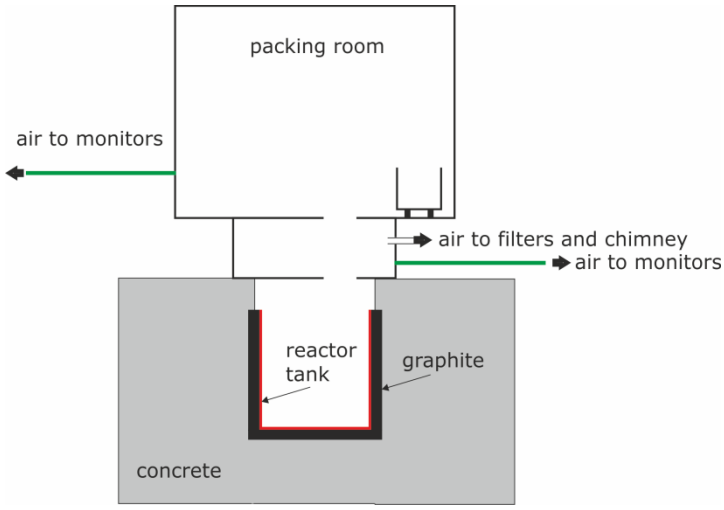

Fig. 1. Schematic cross section of the reactor pit, the packing room and the enclosed space between the pit and the packing room.

It was observed several times during the cutting that there was a correlation between an increase in count rate in the beta-channel of the iCAM monitor and an increase in the gas monitor readings. The filters in the iCAM monitor fairly quickly clogged when activity was released and had to be changed in order to continue monitoring. A clogged filter was analysed at the Center for Nuclear Technologies (Nutech) at the Technical University of Denmark (DTU). The analysis concluded that all the activity on the filter was ^{36}Cl. The correlation between the two detector readings is interpreted as a simultaneously release of ^{36}Cl activity in both particulate and gaseous form when the cutting took place. A direct analysis for gaseous ^{36}Cl was not made, but ^{36}Cl was detected by Nutech in a sample of condensed water from a freezing trap which is situated after the filters at the DR3. From this observation it is concluded that indeed some ^{36}Cl activity was released on gas form and able to pass the filters.

Origin of ^{36}Cl

Analysis on samples have shown that both the reactor tank itself and the graphite moderator contain ^{36}Cl. Content of ^{36}Cl in neutron irradiated reactor graphite is also known from literature [1]. Apart from what is present in the raw materials, ^{35}Cl can also be a leftover from a pre-irradiation (purification) treatment of the graphite with chlorine gas [2, 3, 4]. Part of the ^{35}Cl is subsequently activated during reactor operation. The chlorine treatment of graphite is made at high temperatures and therefore it is reasonable to conclude that heating of some part of the graphite to high temperatures during plasma cutting will release otherwise trapped ^{36}Cl [5].

Determination of releases of ^{36}Cl activity from air monitoring

The readings of the connected gas monitor during the cutting have been used to calculate an upper limit of the release of ^{36}Cl activity, *Q*, to the surroundings for each day of the cutting. This was done (eqn. 1) by assuming that the gas monitor response was due to ^{36}Cl only (ignoring a ^{3}H contribution) and calculate the average concentration during the cutting on the given day, $\bar{C}_{Cl36}$ and multiply this with the length of cutting time, *T*, the ventilation flow rate, F_p, and a factor dependent on the flow model, *k*.

$$Q = F_p \cdot T \cdot \bar{C}_{Cl36} \cdot k \qquad (1)$$

k=1, when the gas monitor sucked air directly from the enclosed space, and *k*=20 when the monitor sucked air from the packing room. Table 1 shows the days of plasma cutting and the

calculated releases for these days. The releases of ^{36}Cl activity in 2017 add up to a total of: 2,7 GBq ± 0,4 GBq.

Table 1. Days of cutting in 2017 and calculated releases of ^{36}Cl

Date (2017)	Release [MBq]	Uncertainty [MBq]	Date (2017)	Release [MBq]	Uncertainty [MBq]
24th Feb.	17	17	3th July	16	4
8th Mar.	3,2	3,2	4th July	114	28
28th Apr.	38	38	5th July	69	17
3th May	42	42	24th Aug.	79	20
4th May.	7,3	7,3	25th Aug.	202	50
5th May	26	26	28th Aug.	322	322
8th May	12	12	29th Aug.	168	42
9th May	4,0	4,0	30th Aug.	70	18
10th May	8,6	8,6	28th Sep.	71	18
15th May	8,3	8,3	29th Sep.	23	6
18th May	57	57	2th Oct.	17	4
22th May	139	139	3th Oct.	15	4
23th May	101	101	4th Oct.	30	7
24th May	28	28	5th Oct.	30	7
29th May	20	20	30th Nov.	15	4
30th May	134	134	5th Dec.	1,0	0,3
6th June	20	20	6th Dec	22	6
8th June	3,0	3,0	7th Dec	5,1	1,3
13th June	34	8	14th Dec	98	25
14th June	43	11	15th Dec	8,5	2,2
15th June	27	7	18th Dec	8,6	2,2
16th June	9,9	2,5	19th Dec	29	7
28th June	253	63	20th Dec	22	6
29th June	53	13	21th Dec	36	9
30th June	179	45			

Upper limit for committed effective doses from ^{36}Cl release

Most exposed individuals under no-wind conditions

The individuals who will receive the highest doses are the ones who are staying close to the release point (23 m chimney). The nearest workplaces are at a distance of ~45 m (horizontal distance). The maximum release rate was ~50 MBq/h and the maximum daily release was ~250 MBq. The highest concentrations close to the release point will occur when there is no wind. The exposure has been modelled with the following assumptions 1) activity is released at a rate ($\dot{q}$) of 50 MBq/h, 2) activity is released into a cylindrical volume (V) of air with a radius of 45 m and a height of 44 m and is homogeneously distributed in the cylinder instantaneously and 3) the air in the cylinder has an air change (λ) of 20 times per hour. The concentration of activity ($C(t)$) as a function of time will using the model follow the eqn. 2:

$$C(t) = \frac{\dot{q}}{V \cdot \lambda} \cdot (1 - e^{-\lambda \cdot t}) \qquad (2)$$

Inhalation of air with a rate of I (1,2 m^3/h) from the cylinder during a 5 hour release will result in an effective dose E, which is calculated from eqn. 3:

$$E = \int_0^{5h} \frac{\dot{q}}{V \cdot \lambda} \cdot \left(1 - e^{-\lambda \cdot t}\right) \cdot I \cdot e_{50} dt \qquad (3)$$

where $e_{50} = 7 \cdot 10^{-3}$ µSv/Bq is the dose conversion factor for inhalation of ^{36}Cl.

The effective dose is ~ 0,5 μSv for the total release of 250 MBq during the 5 hour release.

Most exposed individuals in windy weather

In windy weather released activity will be transported in a plume from the release point in along the direction of the wind (downwind). At some distance part of the plume will reach the ground level. At the closest distance to the point of release at which the plume reaches the ground the air concentration of activity will be at maximum. The dispersion of the plume can be approximated by the Gaussian dispersion model. For most common wind conditions the maximum concentration at ground level will be ~400 m in horizontal distance from the release point (downwind). For neutral atmospheric stability conditions, a wind speed of 5 m/s, a release rate of 50 MBq/h, the maximum activity concentration at ground level can be calculated to ~0,5 Bq/m^3 (*C*). If the wind direction is unchanged a release lasting 5 hour (*T*) will result in an effective dose of

$$C \cdot I \cdot T \cdot e_{50} = 0{,}5 \cdot 1{,}2 \cdot 5 \cdot 7 \cdot 10^{-3}\ \mu\text{Sv} = 0{,}02\ \mu\text{Sv} \qquad (4)$$

For the same release, the effective dose at a distance of 1 km from the release point in the direction of the wind is ~0,01 μSv.

Determination of releases of ^{36}Cl activity from grass sampling

One grass sample was taken close to the release point and another one was taken ~450 m from the release point where deposition will be at maximum given the most common wind and atmospheric stability conditions. Nutech analysed the samples and found no ^{36}Cl. Upper limits for ^{36}Cl activity deposited pr. unit area were established from the detection limits. From the upper limits for deposited activity pr. area upper limits for total released activity could be calculated.

Upper estimate for total release during the no-wind condition

Using the model mentioned in the previous section for the no-wind condition and a dry deposition velocity from air to grass: $v_d = 10^{-3}$ m/s, the total release, q, is related to surface activity concentration, σ, as:

$$q = \frac{V \cdot \lambda}{v_d} \cdot \sigma \qquad (5)$$

With an increased cylinder volume, *V*, (radius=height=70 m) because the grass sample had to be taken at a closest distance of approx. 70 meter from the chimney, the upper limit for total the release is calculated from eqn. 5 to be ~ 0,5 MBq. The calculation has a large uncertainty (estimated higher end of 90% C.I.: 50 MBq).

Upper estimate for total release during windy conditions

Using the Gaussian model (neutral atmosphere stability conditions, wind speed 5 m/s) and a dry deposition velocity $v_d = 10^{-3}$ m/s, the total release (q) is related to surface activity concentration (σ) at ~ 450 m from the release point as:

$$q = \frac{\sigma}{4{,}5 \cdot 10^{-8}}\ \ \text{Bq}^{-1} \cdot \text{m}^{-2} \cdot \text{Bq} \qquad (6)$$

From eqn. 6 the upper limit for the total release in the most frequently occurring wind direction is calculated to be: ~1MBq. The calculation has a large uncertainty (estimated higher end of 90% C.I.: 100 MBq).

Conclusions

Air monitoring revealed that plasma cutting of the DR3 reactor tank released ^{36}Cl both in particulate and gaseous form. Literature suggests that most of the ^{36}Cl is due to activation of stable chlorine which was left over from a pre-irradiation treatment of the graphite with hot

chlorine gas. The released ^{36}Cl gas can penetrate the exhaust filters and be released to the surroundings. From gas monitor readings (assuming that the gas monitor readings is caused by ^{36}Cl only) an upper limit of the total released ^{36}Cl activity to the surrounding can be calculated to 2,7 GBq ± 0,4 GBq. Effective doses to individuals in the surroundings from the released ^{36}Cl are very low. Effective dose to a given individual during the period of cutting is estimated to be < 1 μSv. No ^{36}Cl activity was found in grass samples and suggest (although with high uncertainty) that the actual released ^{36}Cl activity has been very low.

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S8-O4

Difficult to measure beta emitters (55Fe and 63Ni) in activated pressure vessel steel – theoretical versus experimental analysis

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For preparing to gradual nuclear reactor decommissioning and gathering radioanalytical knowhow on characterization of activated materials, a pilot research project VAMMA was performed in co-operation between Helsinki University and Technical Research Center of Finland as a part of KYT 2018 research program in 2018. Characterization of activated materials require non-destructive analysis for gamma emitters, namely gamma spectrometric analysis, and destructive analysis for alfa and beta emitters, namely radiochemical analysis. Due to the radiochemical analysis requirements (e.g. complete destruction of the material, radiochemical separation of the radionuclide from the matrix and other radionuclides), these radionuclides are often referred as difficult to measure (DTM) radionuclides. The main goal of the analytical part of the project was to find a functional separation method for determining 55Fe and 63Ni, often the most abundant DTM in activated pressure vessel steel, and compare the experimentally obtained activity concentrations to corresponding values from computational methods. Additionally, studies on 14C analysis was also carried out. Gamma measurement of solid steel pieces were done both with standard geometry calibration and ISOCS (In Situ Object Counting System) calibration. Also the activity concentrations of 55Fe and 63Ni measured with liquid scintillation counting (LSC) after radiochemical separation of those isotopes were compared with theoretical values calculated based on the irradiation history of the steel and known composition before irradiation. The experimentally determined radionuclide concentrations will eventually be utilized in calculating the scaling factors and estimating the validity of mathematical models.
The radiochemical analysis of 55Fe and 63Ni was challenged by abundant amount of iron and 60Co and thus the radioanalytical method development will continue in a new four-year DEMONI project (funded by KYT 2022 research program). Validation of the results will be carried out via DTM-DECOM project (funded by NKS-B program), in which an intercomparison exercise on analyzing 55Fe and 63Ni from steel will be executed among several Nordic laboratories and one non-Nordic partner during 2019. The key findings of the pilot study are being summarized for a scientific article and they will be discussed in the presentation.

S8-05

Radiation protection of the decommissioning Hot Cells

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Introduction

Decommissioning of the Danish hot cells facility has been delayed and restarted after an initial decommissioning in 2002, where the six main hot cells were left entombed. All auxiliary equipment such as the ventilation system was dismantled. Around 2010 the work on decommissioning the hot cells was restarted and the framework of the decommissioning project was written. And a new ventilation system was built. For some reason the project was halted around 2012. In 2014 the project was restarted again with a new planning crew. The primary task of the project is to decontaminate the 6 main Hot Cells. And in 2017 the actual decontamination began and activity has been removed from the hot cells. As of today the initial remote decontamination phase has finished and a preparation for the second decontamination face is started. This phase entails manual labor inside of the cells.

Purpose

The purpose of this extended abstract is to share the main experiences gained from the radiation protection of the decommissioning of the Danish hot cells facility at Risø. The project framework is discussed.

Project framework

The framework of the project is setup by Danish Decommissioning (DD) and the Danish authorities. The setup resembles a stage gate model typically used in project management. Before a major decommissioning project is allowed to start by the Danish authorities, a project description has to be made. This document serves as the project charter and must include a description of the project in terms of milestones and the goals and overall activities of the milestones. In addition, a simplified safety analysis has to be carried out. Once the authorities have approved the project charter, DD can initiate planning the work, which have to be done in order to reach the milestone. This plan has to be documented in a subproject description, where a more detailed description of the activities necessary for completing the actual phase of the project. This document must provide a risk analysis of the activities and remediation steps planned in order to reduce potential doses to workers. Once the authorities have approved this subproject description detailed work operations can be planned. These project operations are documented and sent to the authorities in order to acquaint the authorities with the planned operations. The authorities do not need to approve these operation plans, but they are obviously entitled to halt the operations if they find it necessary. Once the milestone has been reached, work on the next subproject is started. This adapted stage gate model differs from typical commercial projects in the fashion, which in typical projects the results achieved in the given stage is evaluated and the possibility of completing the project successfully is assessed, whereas the plan and risk assessment of each stage is evaluated in the adapted stage gate model. An optimisation of possible doses has to be shown in order to engage a given stage. This adapted stage gate model is a very good model to ensure that possible doses have been optimised. The model is very well suited for decommissioning projects.

Applied radiation protection experiences

In this section some important experiences of the radiation protection work is shared. In DD, the radiation protection group is placed organisationally in an independent organisation without any operational responsibilities. The radiation group thus serves as an internal advisory and supervising organ with the mandate to halt any operations if proper radiation protection measures are not properly followed. There is a main health physicisist (RPE) and health assistant (RPO) attached to the project.

Although having an advisory and supervising role the health physicist of the hot cell project participates actively in all aspects of the planning in the project and in the execution of the operations. The primary focus of the health physicist during the planning phase is to play the devil's advocate and challenge the solutions in order to optimise the possible doses. The Project engineers has silently learned from this approach and have begun to think dose optimisation into the planning work. In addition, during execution, the project engineers have learned to continually think about reducing doses and they are continually making small changes to optimise the doses to the workes.

A very important radiation protection step during execution of long-term operations was to introduce a weekly cleaning day where the working areas are cleaned. This notion was not readily accepted by the engineering team, because of the reduction of operation time by 20%. However, it was slowly accepted. And in the end it became a combined maintenance and cleaning day. During the first decontamination work no incidents happened and the working areas were successfully kept clean. This have prevented that the background radiation of the working areas steadily rises due to build-up of contamination.

Another related but also very important radiation protection step is the way the workers perform. The workers in the hot cells project are very aware of minimizing contamination as this effectively reduces the external doses but most importantly the risk of internal doses. So they are working meticulously spreading plastic sheets out under areas that are susceptible for being contaminated and removing the sheets after the operations and cleaning the areas ensuring that the area is clean before the proceed with the nest operation. This way of working have resulted definitely reduced the external doses to the workers along with reducing risk of internal doses as the work areas are kept clean.

The daily hygiene is a very important radiation protection tool, which must not be neglected.

The use of mock ups is also an important tool to prepare the workers for tasks that are more complex and as a planning tool. During planning stages, mock ups are useful to test the sequence of different tasks or to illustrate possible flaws in an operation. E.g. when the planning how to take the protection suit off after entry in the hot cells a simple mockup of the planned rooms and auxiliary tools helps in determining the safest sequence of operations. Another example is a 1:1 mockup of the filterhousing used to train a safe change of filters. The change procedure of these particular filters was quite difficult. The use of the mock up resulted in a substantial decrease of time used to change the filters. The time was reduced by a factor of 4 from the first attempt to the first actual filter change. As a side effect, the training procedure provided a better estimation of the time of operation and thus the possible doses during the work.

Conclusions

The project frame work, with an adapted stage gate model, used in Denmark is very suitable for controlling the radiation protection for decommissioning projects.

Essentially the most effective and important applied radiation protection method arises from the workers doing the actual work. Their safety culture and way of working is a paramount parameter for a successful radiation protection scheme. The workers need to understand why and how they can reduce external doses and risk of internal doses. That knowledge must reflect in the way they are working. The presence of the Health assistant is also very important, that is why we have them in the first place.

The second most effective method of applied radiation protection is the engineering team. Simply by, acknowledge the importance of continually thinking dose and risk reduction into both planning and execution. In the hot cell project, an active role of the health physicist in the project helped achieving this.

Mock ups are an effective tool in radiation protection.

Besides the usual supervision and advisory role of the health physicist there is the role of a facilitator of radiation protection, helping all aspects of the decommissioning project to think and live radiation protection. Effective radiation protection is not due to the health physicist but due to the project engineers and the workers, the health physicist has to be able to facilitate this.

S8-O6

Simple Contamination, Comprehensive Solution - a Case Study

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Introduction

The Risø National Laboratory, located in Denmark 30 km West of Copenhagen, is currently undergoing decommissioning, a process planned from 2001 and initiated in 2003 with an original scope until 2023.

Apart from three nuclear research reactors and waste treatment facilities, the site housed a Fuel Fabrication Plant, which was initially decommissioned from 2013 to 2015. The word “initial” is essential, as measurements on removed drains and gutters at basement level showed a contamination with natural uranium, resulting from the production of fuel elements for the DR 3 reactor. As some gutters were corroded, a potential contamination of the floor below, an area spanning 21 square meters, could not be ruled out. It would be necessary to conduct further measurements and evaluation.

Methods

It was necessary to conduct a measurement regime, over multiple periods, with both surface-scraping and drilling.

The affected area has a width and length of 1 and 21 meters, respectively. Figure 1 shows the location within the building, while Figure 2 shows the same view looking at ground level. As the contamination is below ground, it will be necessary to remove large amounts of machinery in order to break up the floor, if direct removal from below ground level is not possible.

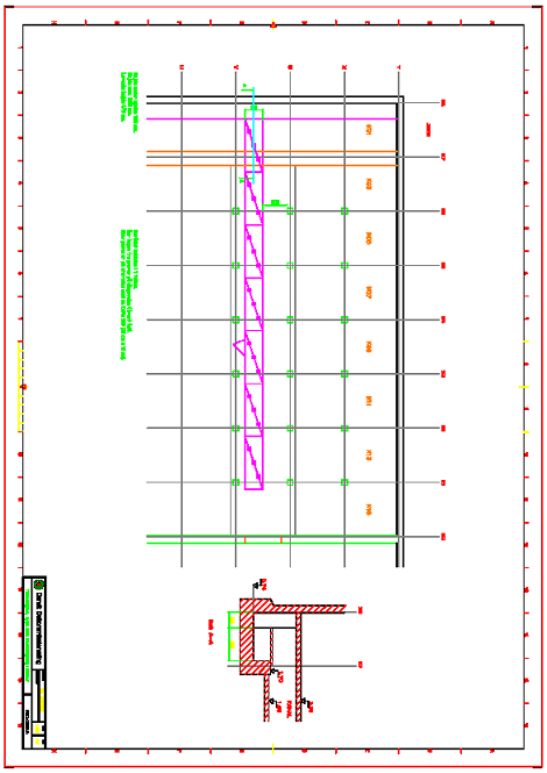

Fig. 1. Purple area denotes the contaminated area

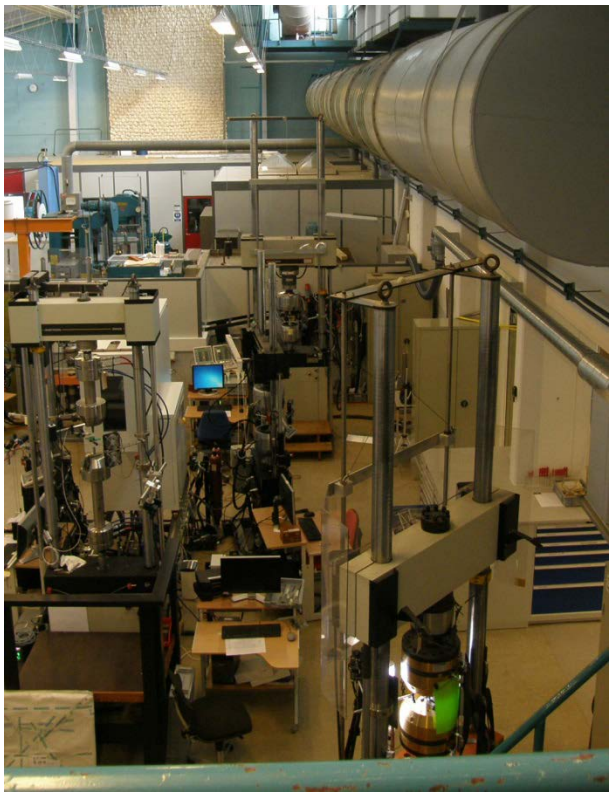

Fig. 2. The area at ground level

Results and discussion

The measurements showed that the contamination had moved into the concrete flooring, concentrated in the middle but measurable to the sides. Based on the drill samples the clearance index for every 2 cm depth was calculated, and based on Danish methods and regulations the top 6 cm were above clearance levels and have to be dismantled and packed as low level radioactive waste. However, with the concrete floor estimated to have a thickness of 10 cm this might prove a challenge.

Conclusions

This rather simple problem resulted in not only sampling and measurements, but also a discussion with the authorities on the issues and principles of clearance, exemption and methodology. In the span between health physics, financial budget, authorities and conventional occupational health and safety, there are lessons to be learned.

S9-O1

A new MiniPANDA detector for measurement of environmental samples

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The MiniPANDA detector has been developed at the Radiation and Nuclear Safety Authority of Finland. MiniPANDA is designed for measurement of environmental samples. It consists of a high purity germanium detector and a silicon PIPS detector within a compact lead castle. MiniPANDA allows for spectral list mode measurement of gamma and alpha radiation. As compared to traditional gamma spectrometry the detection limit for many alpha active nuclei can be enhanced using coincidence techniques to filter out the background. It is operated under normal atmospheric pressure and is therefore simpler and faster to use than conventional alpha spectrometers.

S9-02

Radon concentration in water in Iceland

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Abstract

Radon measurements have a long history in Iceland. The first measurements, performed in 1904 and 1906 in geothermal gases, showed a wide variation in the radon concentration, ranging from 21 to 8258 Bq/L. Recent measurements of indoor air show low radon concentration, which is expected because the Icelandic bedrock is mostly basalt lava that has low concentrations of uranium and thorium

In this work the results from two recent radon measurement series are analyzed. The first series consists of about 100 samples collected in the years 2003 - 2008. The second series consists of 150 samples collected in the years 2016 – 2019, improving the geographical coverage. Samples were collected from various sources of drinking water; cold, lukewarm and warm geothermal springs and boreholes.

Samples in the first series were measured with a liquid scintillator counter, developed at the University of Iceland, with lower limit of detection (LLD) at 0.008 Bq/L. The samples in the second series were measured with RAD-7 (DURRIDGE) with LLD at 0.37 Bq/L. The concentration of radon in Icelandic drinking water is low; 0.3-16.9 Bq/L in the first series and 0.1-8.5 Bq/L in the second. Eighteen samples in the second series were below detection limit. In the first series, more than 30 other parameters and chemical species were also measured, but no correlation was found with the radon concentration.

In conclusion, even though high concentration of radon have been found in geothermal gases, the radon concentration in Icelandic water is not a significant health issue in Iceland

Introduction

In the summer of 1904 and 1906, an Icelandic physicist at the University of Copenhagen, performed measurement of radon in Icelandic hot springs. His aim was to investigate “to what extend radioactive substances are to be found in the earth, as well as their significance with regard to the earth´s temperature” [1]. Since then, radon measurements in Iceland have mostly been done in association with geological research. The bedrock in Iceland is predominantly basalt that has low concentration of uranium and thorium. The measurements from the beginning of the century were repeated in 1965 and 1966 by the Icelandic Energy Authority (Raforkumálastjóri) and many of the original findings were confirmed. The highest reading were in the area around Geysir in Haukadalur (Litli Strokkur, 6919 Bq/L gas) but most of the results ranged from 10-1000 Bq/L gas. The conclusion was that radon concentration in geothermal gases was higher at high temperature geothermal areas than in low geothermal areas [2]. There has not been much interest measuring radon in indoor air or water in Iceland due to the low uranium and thorium concentration in the Icelandic bedrock. The first measurements of Radon in indoor air were made in 1982, jointly by the Icelandic and Danish radiation protection authorities. Radon measurements performed in the basement of 18 houses in various locations in Iceland showed low radon levels,

as suspected (7.8 Bq/m^3 on average). Radon in hot and cold water was measured at the same locations but all measurements were below the detection limit, 0.4 Bq/L [3].

In 2012-2013 a survey was conducted, where radon measurements were performed inside around 250 household in Iceland, to investigate radon in indoor air for the confirmation of earlier findings and for the estimation of radon dose to the public. The results was as suspected similar to the earlier findings [4]. The previously measured, low radon concentration in water was, on the other hand, yet to be confirmed with new measurements.

Purpose

The purpose of this work was to gather and publish data on radon concentration in water in Iceland, with an acceptable geographical coverage of the country's populated areas.

Methods

In this work there are two measurement series. The first series consists of samples collected mostly between 2003 and 2008 in a survey of radon in water around Iceland, performed by researchers from the University of Iceland and the University of Akureyri (partly at the request of the Environmental agency of Iceland). In the first series, samples were collected from various water sources; drinking water; cold, lukewarm and warm springs, geothermal springs and boreholes. Sample sites were all around Iceland, except from areas in the southern part of Iceland. Samples were taken in airtight 200 ml glass bottles and measured 1-5 days later. Care was taken to minimize radon losses when collecting the water samples. The samples were measured with an automatic system for low-level radon in water developed at the University of Iceland. It is a single photomultiplier tube, liquid scintillation counter with a special multichannel analyzer to measure radon. The radon was transferred to a 15 ml liquid scintillator by bubbling air through the sample and the scintillator in a closed system. When using the special designed multichannel analyzer the system has a lower limit of detection of 0.008 Bq/L in a three hour counting [5]. Along with radon, more than 30 other parameters and chemical species were also measured such as conductivity, temperature, minerals (for example SiO_2), metals (Mg, Fe, Al) and gases (O_2, H_2S) [6]. The radon results from the first series has not been published before as a whole series. Samples in the second series were collected between 2016 and 2019 and were mostly collected from tabs in houses at various location in Iceland. Special care was taken to get a good geographical coverage of the southern part of Iceland for which, for which data was missing in the first series. Samples were taken in airtight 250 ml glass bottles and measured the same day, or couple of days later. Care was taken to minimize radon losses when collecting the water samples. A Rad7 equipment from DURRIDGE was used to measure the samples and all procedures from the manual were used (sampling water and keeping humidity levels low). The Rad7 has a lower limit of detection (LLD) of 0.37 Bq/L with a 20 minute counting time [7].

Results and discussion

The results show a low concentration of radon in all samples, where the highest radon concentration measured was 16.9 Bq/L. Figure 1 shows where in Iceland the samples were taken. The data from the first series (134 samples) is represented with a diamond and the data from the second series with a cross (153 samples). As can be seen in Figure 1, only a few warm water samples were taken in the second series.

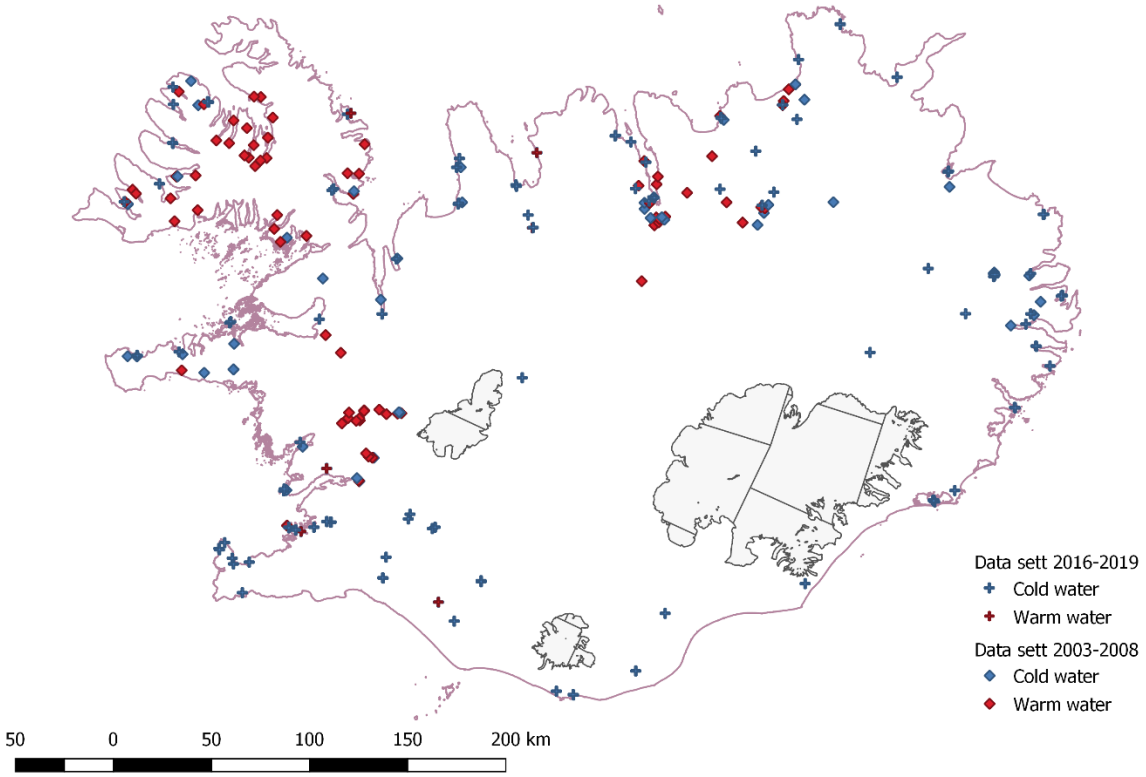

Figure 2: A map of the samples sites in Iceland. The dots are from the 2003-2008 data set and the crosses from the 2016-2019 data set. Cold water is marked with a blue color and warm with red.

The results are presented in a histogram in Figure 2, comparing the two measurement series. The results from the first series (2003-2008) range from 0.3 to 16.9 Bq/L with a median of 2.6 Bq/L and a 3.5 Bq/L average. The second series (2016-2019) ranges from 0.1 to 8.5 Bq/L with a 1.5 Bq/L median and 1.9 Bq/L average radon concentration. Eighteen samples in the second series were below detection limit.

The data from the two series appear similar in the histogram but the second series has proportionally more samples with lower radon concentration than in the first series and all measurements over 10 Bq/L were from the first data set. This might be explained by the fact that almost all the warm water samples were in the first series.

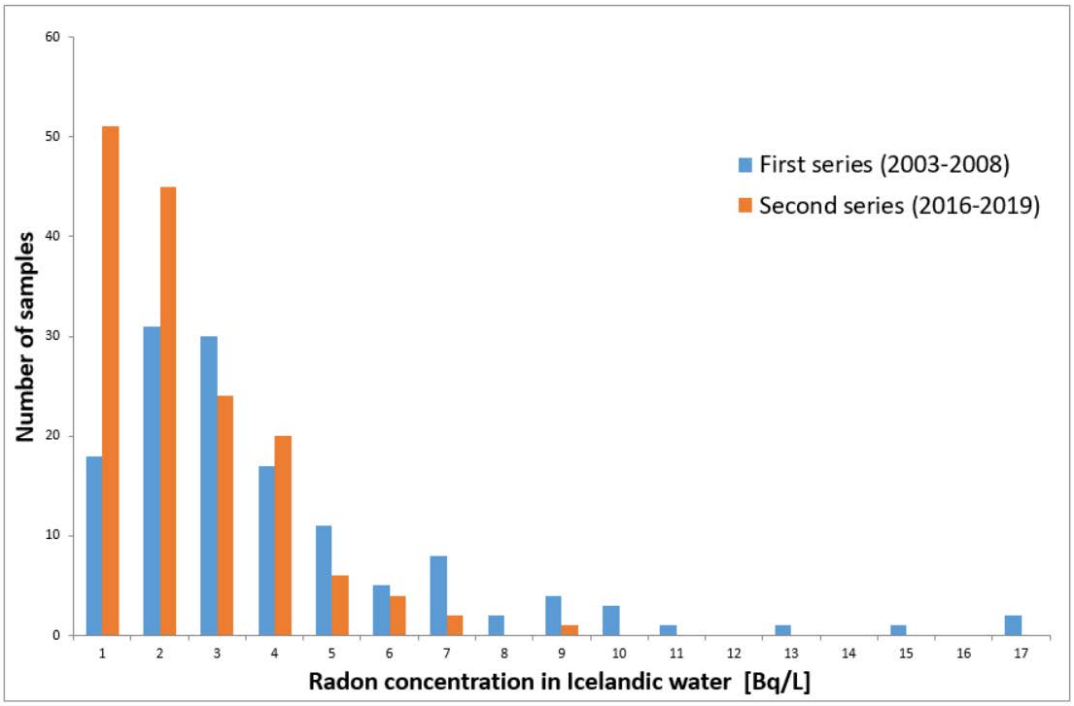

Figure 3: Histogram of the results from the radon measurements.

Figure 3 shows the radon concentration of the warm and cold water samples from first series. The four highest results originate from warm or hot geothermal boreholes which might explain higher radon concentrations because radon gases might come up with the water. Measurements of radon in geothermal gases show high radon concentration. That does not necessarily mean that there are high radon concentration in the geothermal water itself since the high water temperature will result in lower radon solubility in the water.

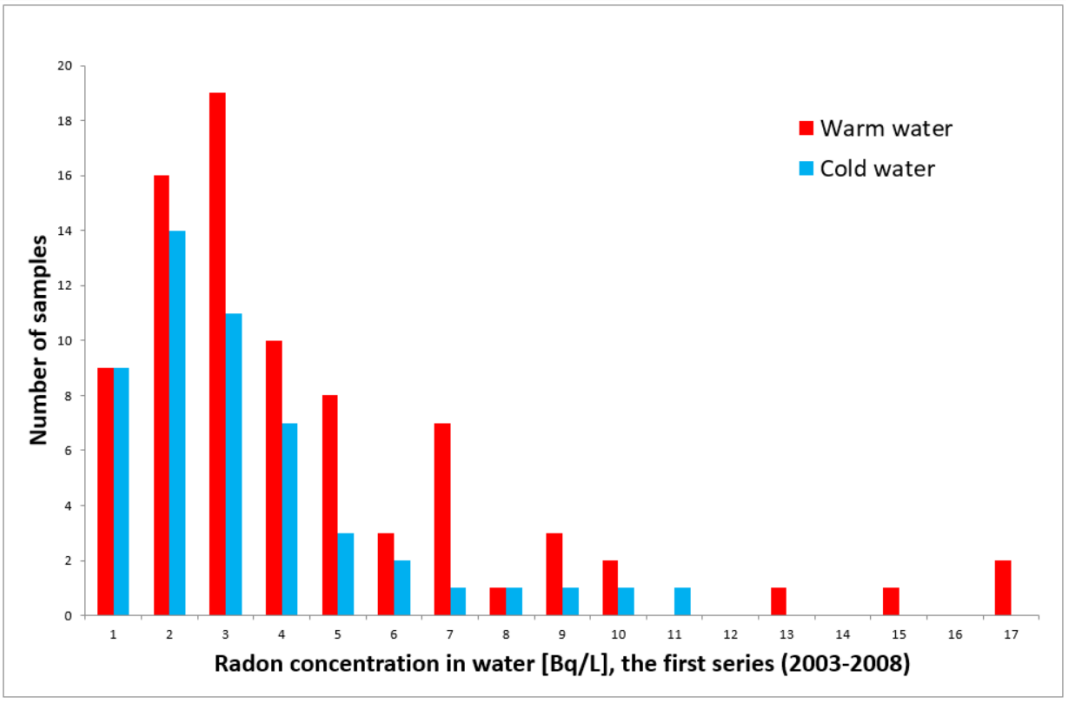

Figure 4: The radon concentration of the warm (red) and cold (blue) water samples from the first measurement series.

No correlations between radon and other variables measured in the first data set was found.

When the results are compared to a geological map no definite pattern is found between the radon concentration and the type or age of the bedrock nor between the radon concentration and the areas of higher natural radioactivity.
The maximum limit for the radiation dose to the public from radon in drinking water in Iceland is 0.1mSv/year. There is no limit for radon activity in the water. With simple calculation it can be shown that the radon concentration in Icelandic water, measured in this study, results in a much lower dose that the specific dose limit [8]. According to the European Council Directive 2013/51/EUROATOM the suggested paramedic value for radon is 100 Bq/L. The highest results found in this work are 6-10 times lower than the suggested paramedic value set by the European Council.

Conclusions

The concentration of radon in Icelandic water is very low, as was expected. It can be concluded that even though high concentrations of radon have been found in geothermal gases, the radon concentration in Icelandic water is not a significant health issue in Iceland.

Acknowledgements

The authors like to acknowledge Páll Theodórsson professor emeritus at the University of Iceland who passed away in January this year (2019). He developed the equipment that was used to measure the first data series with Guðjón Ingvi Guðjónsson and was involved in radon measurements in Iceland for decades. He made all the measurements for the first series along with the first author of the paper. We also want to give thanks to the people at the Public Health districts around Iceland that helped collecting some of the samples.

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S9-O3

Assessment of the radiation environment around the European Spallation Source before its start

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The European Spallation Source (ESS) is under construction in Lund, Sweden. When in full operation (prel. 2023) it will be one of the most powerful spallation sources in the world. During normal operation the facility will produce a large number of radionuclides, some of which will partly be released to the environment. For discharges of radioactive substances by any nuclear facility in Sweden (including ESS), the Swedish Radiation Safety Authority (SSM) requires that the annual effective dose to members of the public must not exceed 0.1 mSv. In order to identify such small dose contributions in the surrounding environment it is of utmost importance to have well-defined baselines for the various components of the radiation environment prior to operation of the facility. For this purpose, Lund University has carried out a first "Zero Point" assessment program in 2017 and 2018 on behalf of ESS. This program has included a survey of natural and man-made gamma-emitting radionuclides as well as pure beta-emitters (^{3}H and ^{14}C). The majority of the assessments and samplings were carried out within 1.5 km from ESS, and included: measurements of the ambient dose equivalent rate in air; gamma spectrometry (stationary and mobile); gamma spectrometry of soil samples, bioindicators, grass, crops, milk, sewage sludge; ^{3}H measurements of samples from various water bodies, of bioindicators and milk; ^{14}C measurements of annual tree rings, grass, bioindicators and fullerene soot monitors. Here we present the design of the Zero Point program, discuss the results, and suggest continued monitoring.

S9-O4

A radionuclide model for the main basins of the Baltic Sea – Identification of representative biota

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Abstract
The Baltic Sea is characterised by a high degree of freshwater input and limited oceanic connection that results in brackish water that hosts rather distinct biota communities, and its environmental protection values are widely recognised. The area has also received its share of the global fallout and deposition from nuclear accidents and, consequently, the radioactivity concentrations in the seawater, sediments and biota, as well as in river waters discharging to the sea, are considerable. Furthermore, the catchment area hosts a number of nuclear installations and population centres with hospitals and other sources of radioactivity, and the sea is travelled occasionally by nuclear-powered vessels. Consideration of the environment by its own right has currently been included in the international radiation protection system, implying explicit consideration of radiation exposures to plants and animals in the area.

For versatile assessments, both commercial and research-oriented, EnviroCase Ltd. is investing in the development of a modern and flexible radionuclide transport and exposure model of the main basins of the entire Baltic Sea. This contribution addresses the identification of representative biota for holistic assessments of radiation exposures of the environment. For this, multiple criteria to choose a practicably limited set of a few organisms representing the distinct brackish-water communities better than the globally used default salt- and freshwater reference organisms, to serve research needs and gaining confidence among ecological sciences, will be established here primarily based on scientific literature preceding and parallel to the default calculation approaches, and applied to the particular conditions of the Baltic Sea.

Introduction
The sources of radioactivity into the Baltic Sea include (e.g. [1]): *i)* natural radioactivity both in the sea itself and coming in as runoff from the catchment; *ii)* radioactive fallout and runoff from nuclear weapons tests and the Chernobyl and other nuclear accidents; *iii)* nuclear reactors in operation, under construction, planned, closed or under decommissioning, many of them releasing effluents directly to the Baltic Sea, as well as via dispersion and deposition of atmospheric releases; *iv)* other nuclear-cycle facilities (fuel manufacturing, waste disposal); *v)* research and medical facilities utilising radioactivity; *vi)* industry dealing with naturally occurring radioactive materials (NORM); *vii)* dumping of radioactive waste; and *viii)* possible accidents with nuclear-powered vessels or nuclear waste transports.

There readily are several models, with varying resolutions and level of detail, developed to simulate the radionuclide transport and radiological implications in the Baltic Sea, some of which even incorporate dynamic food web models (e.g. [2]). There are also a number of individual surveys and status assessments that have been conducted, some of them including also the Baltic

Sea biota (e.g. [1]), as well as ecosystem models aimed at simulating community dynamics (e.g. [3]). However, the availability and/or applicability of these models to our aims is rather limited.

Purpose

The purpose of the overall Baltic Sea model under development [4] is to assess the implications of existing radioactivity and past and future releases both directly to the Baltic Sea and indirectly through atmospheric deposition and runoff from the catchment in the scale of the main basins of the Baltic Sea. This aims at holistic assessments through a framework capable of consistently assessing the exposures of both people and biota by employing deterministic and probabilistic approaches, including thorough state-of-the-art sensitivity and uncertainty analyses. The other model components will be reported elsewhere, and here the focus is on the identification of the representative plant and animal species for the actual sea areas of the Baltic Sea (although not including yet biota exposed mostly through the shoreline habitats; they will be included in the overall model as well, but at a later stage).

Even though the set of ICRP Reference Animals and Plants (RAPs [6]; being also a subset of the Reference Organisms in the European ERICA tool [5]) is considered generally adequate for assessing radiological impacts on biota, it is also recognised that there may be situations in which more specific considerations are warranted for example to address the protection of populations of special interest [6]. The characteristics and distinct biota communities of the Baltic Sea certainly invite further study on whether the generic approaches are sufficiently applicable to it; this is one of study subjects our modelling framework is intended to shed further light into.

Methods

The overall conceptual framework of the radionuclide transport model has been presented in [4]. The radionuclide transport model shall consist of compartments of surface and bottom water, multiple sediment layers in the erosion, transport and accumulation bottoms, and macrophyte vegetation for each main basin of the sea, with inputs from the atmospheric deposition, river and facility discharges and adjoining basins. Also similarly compartmentalised coastal modules will be implemented to address radionuclide transport in coastal bays and shoreline areas.

In the dose rate calculations indicating the degree of radiological exposure of plants and animals, the ICRP recommendations (e.g. [6]) will be followed, with practical guidance drawn from the ERICA assessment tool [5] consistent with these recommendations. As indicated above, these approaches are extended, though, with a supplementary set of calculational organisms representing the Baltic Sea biota communities as outlined in this paper. The calculation methods will remain the same, though.

The ICRP and ERICA documentation, as well as other international approaches, provide a number of different criteria for identifying the reference/representative organisms. These criteria have readily been largely collated in [7, 8] and otherwise are too numerous to be referred to in here due to the limited space; however, all the criteria applied here have been summarised in Table 1 and briefly discussed in the following section. Basically, there is a wide range of potential candidate species, from which the ones best meeting the ensemble of the criteria are chosen. For a short-list of species of various interests, [7–13] were used in support to authors' experience and knowledge. We started by first populating the key positions in a typical Baltic Sea food web [2, 3, 7, 14], and then maximised the representation of the other criteria while favouring species with

higher availability of information (mainly indicated by [12] and initial web searches) and aiming for brevity of the list for pragmatism in respect of the later population of the model with data and the reporting and analysing effort of the results.

Table 1. Representative species selected for the food-web positions typical to the sea areas of the Baltic Sea, with the selection criteria applied and the corresponding globally generic aquatic ICRP Reference Animals and Plants (RAPs) [6] and/or marine Reference Organisms in the ERICA Assessment Tool [5].

Organism type (trophic role in the food web)	Representative species for the Baltic Sea	ICRP RAP / ERICA Reference Organism	Selection criteria				
			Common species	Food-web importance	Exposure potential [a]	Public/conservation interest [b]	Information availability
Phytoplankton	– [c]	– / phytoplankton	x	x	W	–	??
Zooplankton	– [c]	– / zooplankton	x	x	W		??
Submerged macrophyte	Eelgrass	– / vascular plant	x	x	SsW	n	??
Emergent macrophyte	Common reed	– / vascular plant	x	x	SsWwA	–	?
Macroalga	Bladder wrack	Seaweed/macroalgae	x	x	sW	n	?
Detritivorous macrobenthos	*Marenzelleria* spp.	– / polychaete worm	x [d]	x	S	[d]	??
Filter-feeding macrobenthos	Baltic macoma	– / bivalve mollusc	x	x	S [e]		?
Scavenging macrobenthos	*Saduria entomon*	Crab / crustacean	x	x	s		?
Pelagic fish	Baltic herring	Trout / pelagic fish	x	x	W	+	?
Benthic fish	European perch	Flatfish / benthic fish	x	x	sW	+	?
Piscivorous fish	Cod	{Fish [f]}	x	x	sW	+ n	?
Bird feeding on plants	Mute swan	Duck / bird	x	x	wA	+	??
Bird feeding on macrobenth.	Common eider	Duck / bird	x	x	WwA	+ n	??
Bird feeding on fish	Herring gull	Duck / bird	x	x	wA	+	??
Bird, top predator	White-tailed eagle	Duck / bird	x	x	A	+ n	??
Aquatic mammal	Grey seal	– / mammal	x	x	Ww	+	??

a) Coded here through the main environmental (exposure) positions typically occupied by the species: **S** in sediment (burrowed), **s** on the sediment/water interface, **W** in water, **w** on water, **A** in air.
b) Coded here with **+** for positive and **–** for negative public interest (e.g. socioeconomically important and/or emblematic or nuisance species), and **n** for nature conservation interests (e.g. endangered species).
c) No specific representative single species for the phytoplankton or the zooplankton has been identified, but they are planned to be parameterised through typical communities acting in these two trophic roles very fundamentally important to the functioning of the ecosystem.
d) A family of invasive species living relatively deep in the sediment and tolerant to anoxia; possibly competes with the native ragworm exhibiting similar lifestyle and present in decreasing numbers.
e) Also, typical to the soft (accumulation) bottoms unlike the foolish mussel that favours harder substrates.
f) Inhabits both the pelagic and benthic environments.

Results and discussion

As outlined above in the Methods section, the species identification was begun with populating a typical Baltic Sea food web with species common to the Baltic Sea, out of which representatives were chosen by applying the other criteria. Thus, all the representative species can be considered common in the particular environment, and there certainly would have been more to choose from even for each individual food-web position (i.e. trophic role) considered relevant to the present context. Unfortunately, the present reporting template does not allow for elaborating the details, thus pending for further publication. Some guidance applied in the present work also suggest emphasis to be placed on so-called keystone species (e.g. [7, 8]); however, where not readily solidly identified as such in the literature, the identification of such species with higher importance

to the functioning of the ecosystem than obvious would require rather elaborate ecological modelling not feasible within the present project.
Another major consideration in addition to the ecological and food-web relevance is the highest plausible exposure of the species within its group due to its habits, reflected for example in its occupancy in the difference environmental positions (external exposure) and exposure pathways (internal exposure; largely linked to the trophic role, though). Here we have made sure that the ensemble of the representative species covers all the main environmental positions and, as far as practicably possible, their combinations (Table 1). In addition, non-migratory species have been chosen instead of migrating ones to maximise the time of presence (i.e. duration of external and internal exposure). Further exposure characteristics to be considered would include species that are transitory between biotopes or those with prolonged seasonal occupancy for example due to particular life stages or wintering in sediment burrows; these are more characteristic to shoreline species, though, and they will be considered in the later stages of the development work.
In addition, sometimes also the radiosensitivity of the organisms has been considered as a potential selection criterion for the representative biota (e.g. [6, 7]). However, as pointed out also in [7], the current information does not allow for a sufficiently detailed ranking of the candidate species as such in this respect. Rather, these considerations can be hosted more appropriately in broader taxonomic levels, for example through emphasising mammalian and other vertebrate species over invertebrates, and animals over plants. The outcome (Table 1) does reflect such tendency, even though actually already stemming from considering the other criteria first.
Further selection after all the other criteria could be made, in principle, by favouring species with more solid radioecological data readily available. In practice, however, there usually is little room in this respect as also indicated in [5] – with the exception of radiocaesium in many of the trophic roles.
Compared to the ICRP and ERICA selections (Table 1), our set of representatives for the Baltic Sea is somewhat more diverse, although not much more plentiful by the number. However, it is to be noted that our ensemble is lacking in sea anemones and true corals, for which the lower salinity in the Baltic Sea limits the habitats to the Danish Straits (a boundary zone to our model; excluded here), as well as amphibians and reptiles that are present on the coasts of the Baltic Sea (to be considered at a later stage as shoreline species).

Conclusions

We have outlined in this paper a selection of representative species for assessing radiological impacts of radioactivity in the Baltic Sea with a holistic, state-of-the-art simulation model under development as a supplementary set to the more generic ICRP Reference Animals and Plants and ERICA Reference Organisms. The model development continues and further specifications and results will be reported in later publications.

Acknowledgements

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S9-O5

Feasibility of a HMO-process in drinking water treatment technology for removing natural radioactivity and avoiding generation of NORM

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Majority of North Estonia gets its drinking water from Cambrian-Vendian aquifer that contains elevated concentrations of naturally occurring radionuclides – ^{226}Ra and ^{228}Ra. During water purification processes these radionuclides together with other contaminants (Fe, Mn, NH_4-N) accumulate in filter material, creating naturally occurring radioactive material (NORM). In Estonia, the quantity of filter material that exceeds the exemption level (1 kBq/kg) is approximately 300 tons and increases yearly. There is no existing national strategy nor practice in managing NORMs, which causes economic, legal and environmental concerns for the water treatment companies as well as for the legislator. However, during an ongoing project, Alchemia (https://www.lifealchemia.eu/en/), under the EU LIFE programme, a technology is being developed to avoid accumulation of radionuclides in the filter material and at the same time guarantee necessary water quality requirements. The technology employs the HMO-process (Hydrous Manganese Oxide oxidation) with an additional filtration of suspensions. A pilot plant has been set up at Viimsi, Estonia. Up to three different purification schemes will be tested. Prior lab-scale experiments using specific dosing of HMO solution and quartz sand filtration demonstrated a removal efficiency over 80% for Mn, Fe and Ra, which assured meeting the drinking water quality requirements. The current pilot scale experiments, where a HMO-accumulated (creating MnO_2 particles) sand filtration scheme is set up, has shown high removal efficiency for Fe and Mn (over 90%), but lower Ra removal (around 50%). Experimental conditions are being adjusted to demonstrate the technical and economic feasibility of the HMO-process in drinking water purification.

S9-P1

Radioecological sample collection in Finland

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The Finnish Meteorological Institute (FMI) has an extensive archived environmental sample collection that can be utilized in research co-operation. The sample matrices include aerosol samples (air filters), deposition samples (evaporation residuals), reindeer tissues (mainly muscle, liver, kidney and bone), lichen, peat, plants and miscellaneous other environmental samples since the year 1960. The number of air filters and evaporation residuals is about 100 000 and the number of other samples about 1500.
Besides radioecological studies, the archived environmental samples can be used in ecotoxicological research. For example, archived air filters have been analysed for sulphate, methanesulfonic acid, trace metals, lead-210, black carbon, transuranium elements and fission products. Most of the samples are from Finland but there are a small number of samples from the Arctic Ocean and Arctic Russia. The samples are available for joint research projects and graduate works utilizing these samples.

In addition to the sample archive, the FMI and University of Helsinki can contribute to sample analysis with radiochemical separation methods, gamma and alpha spectrometry, liquid scintillation counting, and ICP-MS.

S9-P2

Nuclear contamination sources in surface air of Finnish Lapland in 1965-2011 studied by means of ^{137}Cs, ^{90}Sr, total beta activity, ^{238,239,240,241}Pu, and ^{241}Am

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Air filter samples collected in Rovaniemi were analyzed for investigating origin of anthropogenic radionuclide contamination in the surface air of Finnish Lapland during 1965-2011. This time period covers several nuclear events, including atmospheric nuclear weapons testing, Chernobyl and Fukushima accidents, leakages from underground nuclear weapons tests in Semipalatinsk in 1966 and in Novaya Zemlya in 1987, and atmospheric nuclear weapons tests in 1965-1980. First, total beta activity and ^{137}Cs were measured from the air filters and then ^{90}Sr, ^{238,239,240,241}Pu, and ^{241}Am were separated from each other and matrix by extraction chromatography and anion exchange. The activity concentration of ^{90}Sr was determined with LSC (liquid scintillation counting) and of ^{238,239,240}Pu and ^{241}Am with alpha spectrometry. The mass ratio ^{240}Pu/^{239}Pu was measured with SF-ICP-MS (sector-focusing inductively coupled plasma-mass spectrometry).
The origins of anthropogenic radionuclides in the surface air of Rovaniemi were detected from atmospheric nuclear weapons testing in 1950's -1960's, accidents of Chernobyl in 1986 and Fukushima in 2011, leakages from underground nuclear tests in 1966 and 1987, the SNAP-9A satellite accident in 1964, and single atmospheric nuclear weapons tests performed in 1965-1980. The contamination source varies during time and according to radionuclide. Lighter elements like ^{137}Cs were transported from the destroyed Chernobyl reactor to Finnish Lapland, while only minute amounts of heavier intermediate (^{90}Sr) and refractory elements (^{238,239,240,241}Pu) reached the northern part of Finland.

S9-P3

Radioactivity on peatlands: ecosystem approach on late-phase fallout situations

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Pristine mires are a source of many ecosystem services and natural resources. Their utilisation has been wide and efficient, and this has led to a remarkable reduction in certain mire types and diversified habitats. Consequently, many species of mire vegetation and occupying fauna species have become endangered.
In nuclear accidents, or other radioactive fallout, peatlands not only effectively retain the direct atmospheric deposition, but often also receive, buffer and store radioactivity carried in by surface and ground waters due to their high retention capacity and inherent location in the wetter areas of the landscape. Exposure of humans in such conditions have readily been studied to an extent, but the current radiological protection paradigms also call for consideration of the ecosystems for their own sake after the emergency phase has passed. For the radiation exposure of biota, food webs and intake are typically important factors, but also the external exposure may play a role. Furthermore, in addition to the resident individuals, migrating or visiting fauna may get exposed as well, although to a smaller but not necessarily ignorable extent. Also, the environment itself is a mixture of terrestrial and aquatic types of habitats, the open-water areas often acting as hotspots. In this presentation we outline the consequences of radioactive fallout in terms of radionuclide distribution, and how the earlier anthropocentric assessments could be improved to better address the environmental protection goals in the longer-term existing exposure situations. We also discuss briefly on the role of potential countermeasures in such contexts.

S9-P4

Airborne lead-210 and stable lead in Subarctic Finland 1964-2013

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As a response to the global fallout from the intense atmospheric nuclear test detonations in the latter half of the 1950s the Finnish Meteorological Institute started monitoring activities for atmospheric radioactivity in 1959. From almost the very beginning the collected aerosol samples were archived for future use. In this work we analyzed ^{210}Pb and the stable lead content of aerosol filters from Kevo (69°45'23"N, 27°00'30"E, elevation 98 m above sea level) collected between 1964 and 2013. The purpose of the study was to investigate factors affecting the ^{210}Pb activity concentration and the specific activity of lead (the ratio of the ^{210}Pb activity to the stable lead mass, unit kBq/g Pb) in surface-level air in Subarctic Finland. The ^{210}Pb content of the samples was determined via the in-grown ^{210}Po. The stable lead content of the filters was analyzed with ICP-MS.
The weekly ^{210}Pb activity concentrations were lognormally distributed with a median value of 120 µBq/m³. About 1 per cent of the results were below the detection limit of ca. 20 µBq/m³. The maximum weekly activity concentration observed was 1560 µBq/m³. The specific activity of lead was about 20 kBq/g Pb in the 1960s and the 1970s. When the lead content of the automotive petrol was reduced in the early 1980s the specific activity of lead rose to a level of about 50-100 kBq/g Pb. In 1994 the use of leaded fuel was banned in Finland and the specific activity of lead rose further and reached occasionally values exceeding 150 kBq/g Pb.

S9-P5

Aiming for Accreditation in Gammaspectrometry

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A measurement laboratory shall demonstrate a number of quality assurance virtues, in order to claim competence as outlined by the ISO17025 standard as requisite for accreditation. For the technical part, this includes method validation, registrations, well-defined operations, QC routines, interlaboratory comparisons a.o.

Gammaspectrometry is a method for analysis for radionuclide content and quantity. Either in processed samples of known composition and dimensions or in “rouge” samples with complex structure (geometry) and limited knowledge about materials and composition.

The laboratory at SIS performs analysis of both types of samples, often accompanied by a broad scope of identifying and quantifying any radionuclide present. The lab mostly serves national radiation regulators and officials, as an in-house service, and contributes at inspections, risk-assessment and emergency preparedness.

Gammaspectrometry rely on many variables, selected or entered by the user. To qualify for accreditation the following has been done:

1. All potentially influential variables have been identified, through conceptual mapping of workflow and information pathways.
2. A system was developed, that tracks and document all variables.
3. An accessory databases with dates and status for calibration, validation and maintenance was made.
4. A reporting template was created, which merges results, variables and accessory data and performs QC routines based on stated criteria.

We present examples of some of the developed tools for quality assurance and systems intended to raise the labs level of competence. As concomitant gain, the work has also minimized manual data handling and dependence on human memory, increased efficiency and eliminated paper use.

S9-P6

Tritium in the Lund area prior to start of the European Spallation Source (ESS)

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The European Spallation Source (ESS) consortium is constructing one of the most powerful spallation sources in the world at a site located only a few kilometres from the centre of the city of Lund (~90 000 inhabitants) in southern Sweden. The operation of ESS will generate a wide variety of radionuclides. Parts of these may be released to the environment during normal operation and maintenance as well as in potential incidents and accidents. The radioactive hydrogen isotope tritium (3H) – a pure low-energy beta-emitter with a physical half-life of 12.3 years – is expected to dominate the source term from the ESS target station to the environment with an estimated release rate of ~1 TBq/year during normal operation. As the city of Lund hosts several other activities using tritium-labelled compounds and tritium-containing materials, locally elevated environmental concentrations of tritium may occur already today. As part of a project financed by the Swedish Radiation Safety Authority (project SSM2018-1636), Lund University is establishing the baseline level of waterborne tritium in various outdoor and indoor environments in Lund using liquid scintillation counting analysis. In addition to a status report of long-term measurements of tritium in air, precipitation and various samples of surface and ground water, we also summarize the results of measurements in urine in residents of Lund and in tritium-handling workers in the Lund area. These data, obtained prior to operational start of the ESS facility, will serve as important baseline values in future radiological assessments of the tritium contribution from ESS.

S9-P7

Radon measurements in Þríhnúkagígur cave in Iceland

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Study on indoor radon concentration in Iceland was done between 2012-2013 and showed very low concentrations, as expected due to the low natural radioactivity in the Icelandic bedrock. A one day measurement inside the Þríhnúkagígur cave showed high radon concentrations which were later followed up with our study. The cave is a popular tourist attraction between May and October. Tourists descend 120m when exploring the cave but other parts of the cave reach a depth of 200 meters.
Two instruments were used in this study; the commercial RAD7 and the bespoke AutoRadon made at the University of Iceland. The AutoRadon instrument is a liquid scintillator (single tube) detector. The RAD7 ran for 8 days in total, together with the AutoRadon which ran for a longer time, in total for 129 days. The AutoRadon measurements were done on two separate locations within the cave. The sampling period was one hour for both instruments, which resulted in more than 3000 time labeled data points.
The results showed a significant variability in the radon concentration, depending on the measurement location and time. The conclusion is that the atmospheric pressure and perhaps other weather phenomena might have an influence on the radon concentration. A further investigation is required to test this hypothesis by for instance performing an association study between the long term radon data from this study and weather data from the Icelandic Meteorological Office for the same time period.

S9-P8

Variation in uptake of Cs and Sr by 11 cultivars of oil crops

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The nuclear power plant accident at Fukushima Dai-ichi in Japan, 2011 has renewed the realization of risks related to fallout of radionuclides to agricultural crops. The emission of radionuclides into the atmosphere from various sources, such as nuclear power plant accidents and nuclear bomb explosions, can result in the interception and uptake of radionuclides by crops in the agricultural ecosystem. In order to find out if it is possible to choose crop plants with low radionuclide uptake this project aimed at investigate the variation in uptake of caesium (Cs) and strontium (Sr) in 11 cultivars of oil crops.
The 11 cultivars where grown in a climate chamber in a hydroponic system without or with addition of CsCl or SrCl2 for 19 days. Shoots and roots where analysed on Cs and Sr using atomic absorption spectrophotometry.
Most cultivars preferred Cs over Sr. However, there were a tendency that some cultivars had no preferences between the two elements or preferred Sr over Cs. Results showed as well that the concentration of Cs and Sr was highest in shoot compared with roots in all cultivars. Three cultivars had the highest content of Sr in the root part compared to the other cultivars, which had higher concentration of Cs in their root parts. These differences was not found in the shoot, where the content of the two elements was more or less the same in the cultivars.
The conclusion one can draw from this is that it is possible to choose cultivars of oil crops with low uptake of Sr and Cs.

S10-O1

Novel Gamma Radiation Detector for Finnish Early Warning Network

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Early warning networks are a crucial part of preparedness for nuclear accidents. A comprehensive early warning network enables timely detection of abnormal levels of radioactivity in the atmosphere. This is essential for determining the right protective measures needed to minimize the possibly severe health effects caused by the radiation.

Currently early warning networks are largely based on ambient gamma dose rate measurement stations. The networks are sometimes supplemented with spectrometric stations that enable the identification of radionuclides based on the measured gamma ray energy spectrum.

Unfortunately, even the spectrometric early warning stations suffer from two major limitations. First, when the release plume reaches the vicinity of the detector, it is impossible to distinguish airborne radioactivity and fallout components from each other. Secondly, the detector container box may become contaminated with radioactive nuclides. For emergency management it is of utmost importance to know when the air is clear of radioactive materials.

The presentation summarises the progress in development of a new gamma radiation detector instrument that solves these problems. The current work includes testing of scintillator materials in Phoswich configuration and simulation of the performance of a complete detector system. The development of the new detector is done in parallel with the update of the Finnish early warning network. The final detector will be extensively tested and ready to be deployed by late 2021. The work is conducted under DEFACTO project jointly by The Finnish Radiation and Nuclear Safety Authority, The Helsinki Institute of Physics, Estructura de la Materia IEM-CSIC Spain and The Finnish Defence Forces.

S10-O2

Design Principles of Enhanced Dose Rate Monitoring Network e of the Presentation

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Abstract

The Finnish dose rate monitoring network consists of about 260 stations equipped with Geiger-Műller (GM) tubes. Additionally, over 25 are equipped with $LaBr_3$ spectrometers adapted for environmental monitoring. The existing network ”ULJAS” has been in use since about 2005. The current network has been very robust so far. However, some of its components are at the end of their life cycle. This is why STUK decided two years ago to establish a project on the renewal of the network.

In the beginning of the project it was decided that the network will be enhanced rather than completely renewed. The GM tube technology will be retained due to the good experiences with them. There are some disadvantages in the current software architecture that have to be fixed. This applies not only to the monitoring stations but also to the data management in the server side software.

Some comparisons between in-house and commercially available solutions were made. It was decided that STUK will carry on with our own development of software and maintenance of hardware. Additionally it will be investigated if STUK can replace the existing TETRA communication with a more modern solution.

To study the extent of the network some computational network optimization calculations are performed. Also, the spectrometric part of the network will be expanded. There is an ongoing research project in STUK on a new detector that makes it possible to separate the cloud-shine, deposition and detector contamination components of detected radiation [1].

Introduction

The Finnish dose rate monitoring network consists of about 260 stations equipped with Geiger-Műller (GM) tubes. Additionally, over 25 are equipped with LaBr3 spectrometers adapted for environmental monitoring. The existing network ”ULJAS” has been in use since about 2005. The current network has been very robust so far. However, some of its components are at the end of their life cycle. This is why STUK decided two years ago to establish a project on the renewal of the network.

Since 2017 STUK has had a project on enhancing the current dose rate monitoring network. In this paper the design principles of the new network are outlined. Also current status and future plans will be explained.

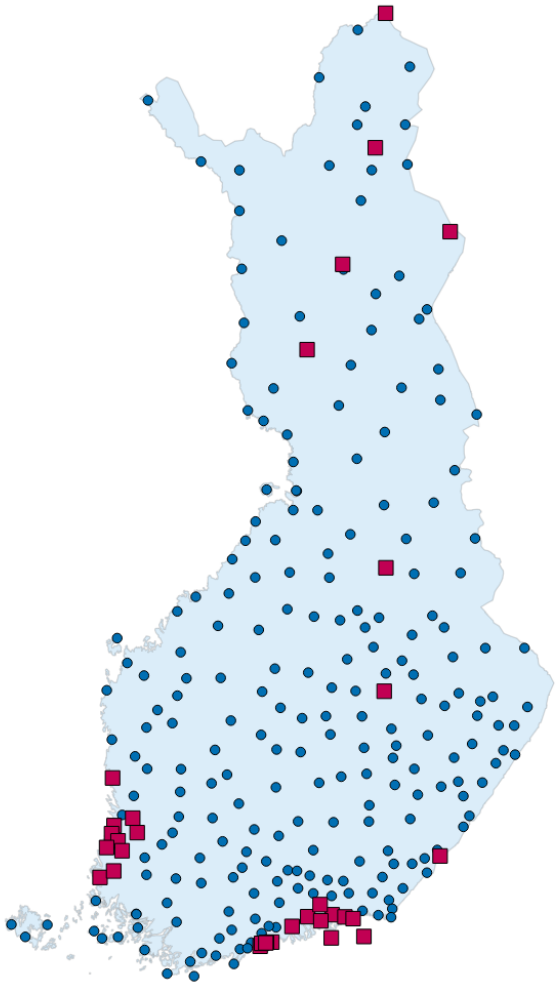

Fig. 1. The current external dose rate monitoring network in Finland. Stations with spectrometric equipment are marked with red squares.

Purpose

In the beginning of the project it was decided that the network will be enhanced rather than completely renewed. The GM tube technology will be retained due to the good experiences with them. There are some disadvantages in the current software architecture that have to be fixed. This applies not only to the monitoring stations but also to the data management in the server side software.

The purpose of the enhancement project is to extend the life-cycle of ULJAS network. STUK and other authorities are currently satisfied with the density and the coverage of the network. The number of stations per capita is the highest and the overall density is one the one of the highest in Europe. By replacing some old technology the network lifetime can be quite easily extended from 10 to 15 years.

Some comparisons between in-house and commercially available solutions were made. It was decided that STUK will carry on with our own development of software and maintenance of hardware.

Methods

The most critical component at the end of its life-cycle is the computer at the measurement station. It is now 15 years old and in the near future it is expected that they begin to break more frequently. The number of different kind of computers have already been tested at STUK. In the market there are a lot of alternatives but it is not easy to find robust computer with low power consumption in the market. The requirement for the station is to keep it running 3 days without external power. The testing of different computer is still in progress. At this point the idea is to make station software independent of computer model.

Data collection and data management software is under reengineering. The current software is not maintainable anymore and more modern programming techniques will be used in the next version of the software. The principle of the software development is make the code more readable and well documented. This makes it possible to have more people familiar with the system which is crucial especially when there's misbehavior in the network.

The current communication between stations is based on governmental TETRA technology ("VIRVE"). It is very secure and robust but unfortunately very slow. In Finland there is an ongoing project to establish a new governmental network based on LTE technology. In this network the data communications would be in regular commercially operated networks but certain traffic could be prioritized. The software and the hardware will be designed to support this new network technology.

In this project the currently well working GM tubes will remain. However in the future the support for at least one model STUK has in use will cease. That's why some irradiation tests with commercially available gamma dose rate monitoring devices including $LaBr_3$ spectrometers will be tested at STUK's irradiation facilities.

To study the extent of the network some computational network optimization calculations are performed. The calculations are based on simulated annealing method. Additionally some intercomparison using DETECT tool [2] will be carried out.

Also, the spectrometric part of the network will likely be expanded. There is an ongoing research project in STUK on a new detector that makes it possible to separate the cloud-shine, deposition and detector contamination components of detected radiation. [1]

Results and discussion

The current timeline is that under 2019 the software for data collection and data management is ready. Then STUK can begin to build a prototype of the new station and test it in a field usage for a while. After some period larger amount of stations will be tested at some selected sites of the monitoring network. Experiences will be collected during that period and modifications for station design can be made based on these tests.

Another major challenge will be project management of such a big task. Due to regulations the buying of the equipment has to be put out to tender. This will require a lot of effort from project participants.

Conclusions

Between 2017 and 2019 STUK will design the hardware and the software new external dose rate monitoring network. From 2020 the assembling of new equipment is made to replace the existing monitoring stations.

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S10-O3

Who Is Emergency Worker? The Finnish Answer

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Introduction

The new EU BSS Directive [1] was given in December 2013 with transposition by member states required by February 2018. One of the new areas of emphasis of the directive is emergency exposure situations. The requirements for this parts have been prepared taking into account the new ICRP recommendations and the lessons from the Fukushima accident.

As part of the articles on emergency exposure situation, the new directive sets out requirements on protection of emergency workers. These include requirements for prior training, radiation protection and monitoring during emergency, and special medical surveillance after emergency.

While the requirements for protection of emergency workers in the directive are unambiguous, the definition of emergency worker is defined in general terms: *“"emergency worker" means any person having a defined role in an emergency and who might be exposed to radiation while taking action in response to the emergency”* [2]. This definition in the directive leaves significant leeway for member states on who are considered emergency worker during transposition of the directive and interpretation of the national regulations.

This paper describes the issues affecting the decision of which groups should be considered emergency workers and the approach taken by Finland during the transposition of the directive.

Emergency worker classification

During emergency exposure situation, especially one that has widespread effects, there are several groups of workers that could be considered for emergency worker status. The groups that clearly are part of emergency workers are rescue service workers and operator’s emergency organization workers. However, as became apparent during the Fukushima accident, there are also other groups that take part in the response to a major accident that are not as easy to classify.

Examples of such groups that straddle the line between emergency workers and public include additional professional workers that might be needed to limit the accident at the site, such as electricians, drivers and assistance in evacuation, workers who maintain critical infrastructure during sheltering indoors, and persons who assist during decontamination. Most of these persons might be difficult to identify before an accident, so it is questionable to what extent they fulfill the definition of emergency workers in the directive, which specifies a person with “defined role in emergency”. However, at the same time these persons would be doing actions that might cause exposure to radiation while taking actions in response to the emergency. Thus, considering them as part of the public does not seem to be correct, either.

Additional problem is caused by the requirement for prior training for emergency workers. The number of possible persons who could end up in the groups described in the previous paragraphs is very large. For example, almost any worker in electrical or water companies might be called to

maintain critical infrastructure during sheltering. Providing the prior training mandated to emergency workers to all of these persons would be impracticably time-consuming and expensive while at the same time any one person would be extremely unlikely to need it. Thus, considering all of these persons as emergency workers would result in impractical and unwarranted large training requirements.

While the above issues mean that classifying all of these persons as emergency workers is impractical, classifying them as part of the public is problematic as well. It is questionable on how great a risk of exposure can be accepted for a worker taking actions in response to an emergency can be accepted, especially since they would not be covered under the same levels of protection and post-accident medical care as emergency workers. Yet, it seems apparent that in a serious accident all of the actions could not be done solely by authorities that are emergency workers.

The Finnish system

To solve the problem presented in the previous chapter, the concept of emergency helpers was included in the Finnish Radiation Act. Emergency helpers are defined are persons who are not emergency workers, but do take part in protective actions or does other work essential to critical functions if society, and might be exposed during the work. Thus, this group includes those workers who would not fulfill the criteria of emergency workers but whose exposure to doses higher than the public would be justified.

The protections given for emergency helpers in the Radiation Act are very close those given to emergency workers. The main difference is that emergency helpers are not required to receive prior training, but they shall be given job briefing with instructions on the risks present and the needed actions to protect themselves. Correspondingly, as they have not received prior training and cannot be considered to have given prior consent to a possible exposure, all actions where they might be exposed must be taken voluntarily by them. In contrast, for emergency workers, who have given their prior consent to risk of exposure, the requirement for voluntarily actions start at reference level of 100 mSv. Finally, in actions where there is a possibility where dose of 20 mSv might be exceeded, emergency workers shall be primarily used. Emergence helpers may be used to do these actions only if they are important for protection of people and they are not possible to be done by emergency workers. Of course, the requirement for voluntary actions applies here as well.

The concept of emergency helpers is close to IAEA's concept of helpers in emergency [3]. For clarity, it should be noted that it is not identical, however. In IAEA's definition emergency workers include both emergency workers designated beforehand, which are same as emergency workers in the Finnish legislation, and emergency workers designated during the accident, which are included in the emergency helpers in Finnish legislation. The same division of workers that is present in IAEA's definition was considered during the drafting of the legislation. However, having the possibility to designate emergency workers during the accident might have caused problems with legal powers versus the subjective rights of the individual being designated. Therefore, it was considered better to include all persons who have not received prior training under the term emergency helpers in addition to those that are considered helpers in emergency in IAEA defintion.

Conclusions

The concept of emergency helpers that was included in the Finnish Radiation Act helps in ensuring that all of the workers that would be present and working during emergency are covered by appropriate radiation protection regulations. At the same time it prevents the interpretation of emergency workers to becoming too wide, which would cause inappropriately large groups of workers from being subjected to the requirements of prior training. Finally, this concept makes it possible to have stricter criteria for exposure for emergency helper, who have not undergone the same level of prior training and acceptance of risk as emergency workers, while making it still possible to have adequate numbers of workers available in case of major accident with widespread need for protective actions.

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S10-O4

Voluntary Radiation Measurement Team

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A large scale nuclear or radiological emergency like a severe accident at a nuclear power plant, use of a nuclear weapon or an explosion of a so called dirty bomb could threat the function of the whole society.
Radiation and Nuclear Safety Authority (STUK) has together with The National Defense Training Association of Finland, (MPK) and National Emergency Supply Agency (NESA) launched a co-operation program to enhance the national radiation measurement preparedness by recruiting, training and equipping a voluntary radiation measurement team. The team will be equipped with diverse and modern measurement tools and it improves Finland's radiation measurement capacity in situations that require plenty of information on radiation in order to ensure safety and support official decision making.
The whole team is assumed to consist of about 40 people divided to three measurement groups and one supporting group. The team will be capable to independently carry out its duties like to determine the radiation situation, to check the contamination of people and vehicles as well as to support other organizations with radiation measurements.
All team members are voluntary. The recruiting of the staff was started in 2017 and the first basic training periods took place in 2018.

S10-P1

Analysis on different hypothetical radioactive release scenarios on Finnish NPPs

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Introduction

STUK is studying the potential radiological consequences from three different hypothetical scenarios using four years of real weather data. All three scenarios are simulated at current Finnish NPP sites: Loviisa 1&2 and Olkiluoto 1&2. Dispersion, dose, and dose rate calculations for each scenario have been made based on historical weather data retrieved from Finnish Meteorological Institute (FMI).

The presentation compares the dispersion of the radioactive materials on the hypothetical release scenarios to current emergency planning zones (EPZs) and operational intervention levels for protective actions in Finland.

The release scenarios can be described as small, medium, and large release. The radioactive source terms used in the modeling is based on realistic radionuclide inventories of the reactors and postulated accident sequences. These source terms give only a scale for the modeling, since accurate source term is unique to each event.

Purpose

The purpose of this study is to give insight to the nature of the possible consequences. The results can be used for the assessment and planning of the possible precautionary and protective actions in a radiological emergency.

Methods

Weather data and release scenarios

The modeling of the releases is based on historical weather data from years 2012-2015. Data is retrieved from Finnish Meteorological Institute. FMI used AROME and HARMONIE operative forecast models throughout this time period. Three release scenarios are used to model small, large and very large NPP accident release. See brief description of the source terms in table 1. Each release is set to begin 00 UTC and 12 UTC for every day during the studied time period. This leads to 2920 repetitions for each release scenario with different weather conditions. Dispersion calculation is performed 48 hours after each release.

95th percentile is used to rule out extreme weather conditions while keeping variance of weather. By doing this the analysis helps the purpose of the study – the weather varies and is difficult to forecast but the stormy winds are that rare it would not be suitable to do analysis and conclusions based on them.

Table 1. Source terms for each studied scenario.

	Loviisa		Olkiluoto	
Case	**Release during the first 3 h**	**Release during the first 12 h**	**Release during the first 3 h**	**Release during the first 12 h**
Small release: 6 hours after the end of the fission chain reaction	• ^{137}Cs: 100 TBq • ^{134}Cs: 147 TBq • ^{131}I: 882 TBq • ^{89}Sr: 3.2 TBq • ^{90}Sr: 0.3 TBq	• ^{87}Kr: 19 TBq • ^{88}Kr: 1000 TBq • ^{133}Xe: 58 000 TBq • ^{135}Xe: 22 000 TBq	• ^{137}Cs: 100 TBq • ^{134}Cs: 109 TBq • ^{131}I: 1000 TBq • ^{89}Sr: 4.4 TBq • ^{90}Sr: 0.3 TBq	• ^{87}Kr: 40 TBq • ^{88}Kr: 2000 TBq • ^{133}Xe: 102 000 TBq • ^{135}Xe: 42 000 TBq
Large release: 1 hour after the end of the fission chain reaction	• ^{137}Cs: 1600 TBq • ^{134}Cs: 2400 TBq • ^{131}I: 15 000 TBq • ^{89}Sr: 52 TBq • ^{90}Sr: 5 TBq	• ^{87}Kr: 3000 TBq • ^{88}Kr: 34 200 TBq • ^{133}Xe: 584 000 TBq • ^{135}Xe: 226 000 TBq	• ^{137}Cs: 2400 TBq • ^{134}Cs: 2600 TBq • ^{131}I: 24 000 TBq • ^{89}Sr: 105 TBq • ^{90}Sr: 7 TBq	• ^{87}Kr: 6000 TBq • ^{88}Kr: 70 000 TBq • ^{133}Xe: 1 029 000 TBq • ^{135}Xe: 454 000 TBq
Very large release: 48 hours after the end of the fission chain reaction	• ^{137}Cs: 16 200 TBq • ^{134}Cs: 23 800 TBq • ^{131}I: 146 000 TBq • ^{89}Sr: 520 TBq • ^{90}Sr: 47 TBq	• ^{87}Kr: 25 600 TBq • ^{88}Kr: 219 000 TBq • ^{133}Xe: 2 920 000 TBq • ^{135}Xe: 1 110 000 TBq	• ^{137}Cs: 24 000 TBq • ^{134}Cs: 26 300 TBq • ^{131}I: 248 000 TBq • ^{89}Sr: 1000 TBq • ^{90}Sr: 72 TBq	• ^{87}Kr: 51 800 TBq • ^{88}Kr: 446 000 TBq • ^{133}Xe: 5 152 000 TBq • ^{135}Xe: 2 257 000 TBq

Dispersion and dose calculations

Dispersion calculations are made using FMI's SILAM atmospheric dispersion model [1]. This study uses SILAM version 5.4 and its Eulerian transport method [2]. SILAM outputs deposition data. Wet and dry depositions are combined.

The dose calculations are post-processed from SILAM outputs using STUK's threat assessment tool TIUKU. For the purposes of this study the effective and thyroid doses are calculated for adults and one year old children from cloud, deposition and inhalation [3, 4]. Radionuclide air concentration near ground level and deposition are used in TIUKU to calculate doses and dose rates. Dose rate conversion factors are retrieved from JRODOS decision support system software and calculated according to ICRP-119 (2013) recommendations.

Results and discussion

Results show that for basic and large cases the current emergency planning zones are feasible. Combined cesium isotope deposition for Loviisa large case is shown in fig. 1. It shows that cesium deposition remains below 1 MBq/m^2 within the 20 km EPZ. Whereas in the very large case – shown in figure 2 – the 1-10 MBq/m^2 area spreads out of the 20 km zone. Note that the figures illustrate all the studied weather scenarios and releases related to them. These illustrations describe the possibility of certain consequences – not a single release scenario.

Operational intervention levels are compared to actual dose. Figure 3 show how the dose in Olkiluoto very large case does not reach 10 mSv during first week for unprotected adult. As a comparison the 100 µSv/h dose rate is exceeded for 48 hours in rather vast area inside the 20 km EPZ. Dose analysis needs more single case study to make further conclusions.

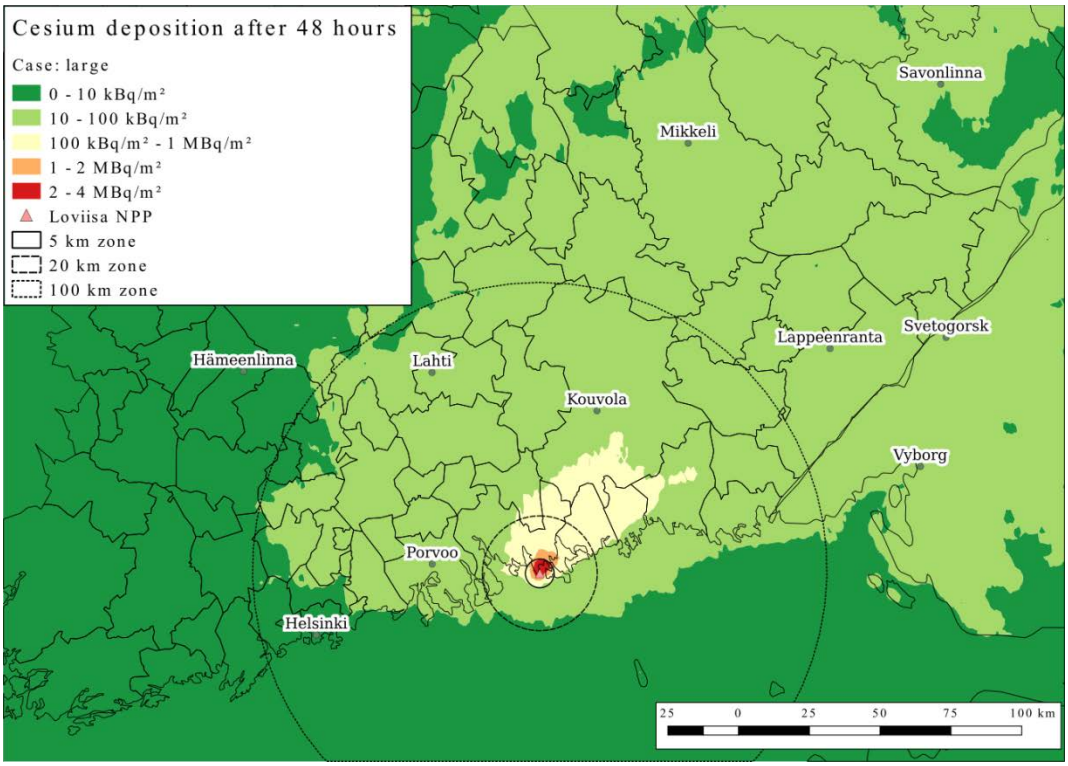

Fig. 1. Combined deposition of cesium isotopes in Loviisa large case.

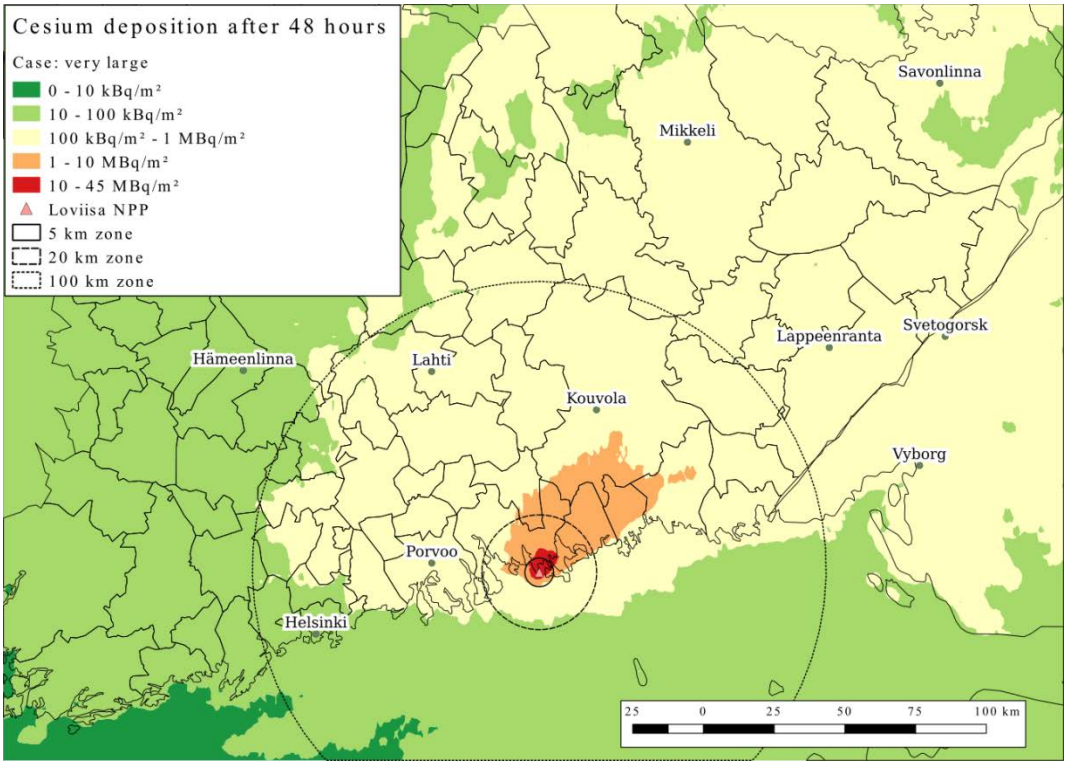

Fig. 2. Combined deposition of cesium isotopes in Loviisa very large case

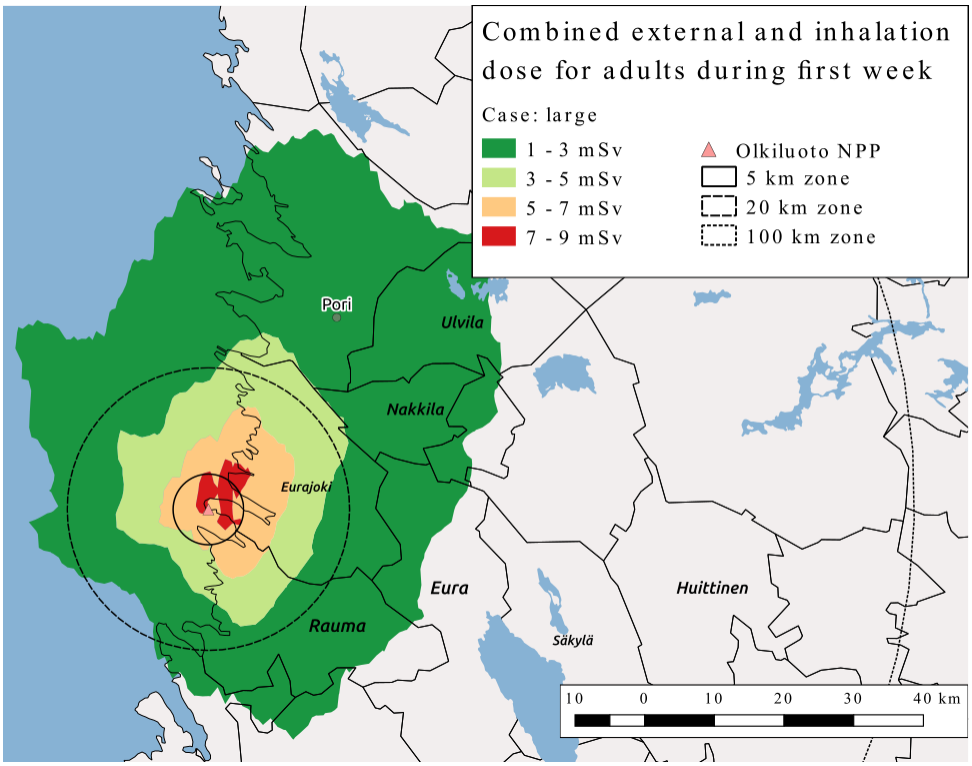

Fig. 3. External and inhalation dose combined during the first week after release for adults in the Olkiluoto very large case.

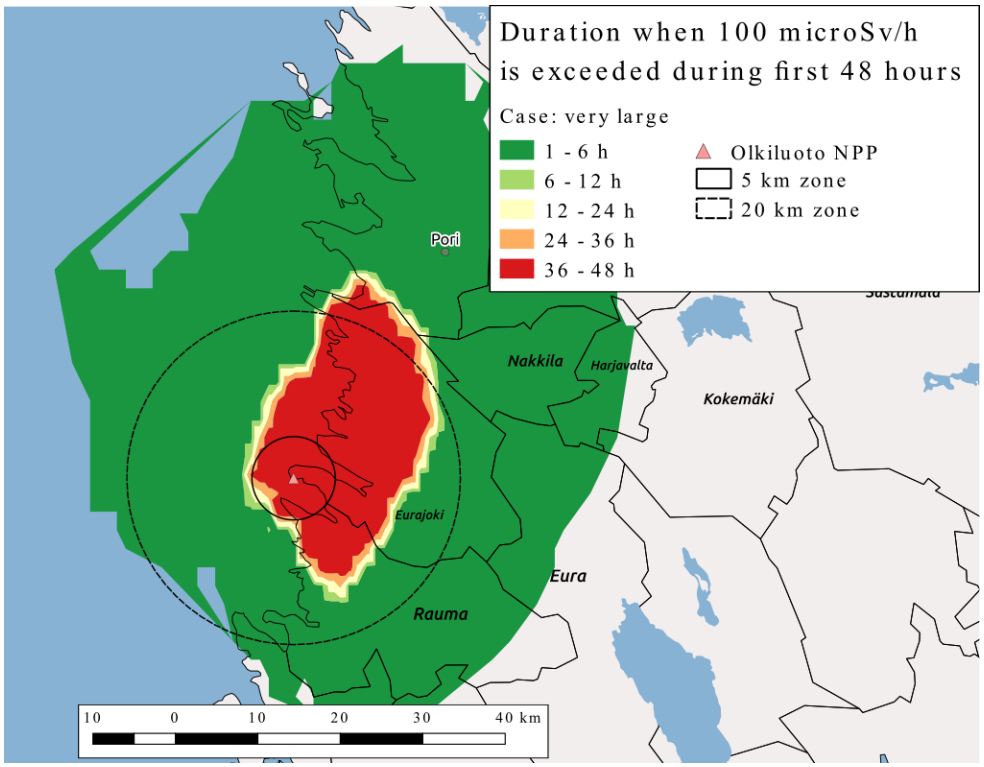

Fig. 4. External and inhalation dose combined during the first week after release for adults in the Olkiluoto very large case.

Conclusions

Study shows that current Finnish emergency planning zones are reasonable. Some advanced preparations could be done in certain extended areas outside the 20 km zones if accident scenarios involving very large direct release to environment are considered. Further study roadmap could be sensitivity analysis, for example seasonal effects on weather and single case study comparisons.

A similar analysis to this is to be performed for the upcoming Finnish NPPs Olkiluoto 3 and Hanhikivi 1.

Acknowledgements

This study is a part of STUK's threat assessment project. Thanks are in order to Finnish Meteorological Institute for the preparing the weather data and for making dispersion model calculations.

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S11-O1

Genomic instability and non-ionizing radiation

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Extremely low-frequency (ELF) magnetic fields have been classified as possibly carcinogenic to humans, mainly based on rather consistent epidemiological findings suggesting a link between childhood leukaemia and 50–60 Hz magnetic fields from power lines. However, the causal relationship between such fields and childhood leukaemia is still unclear, as animal and in vitro experiments have provided only limited support for carcinogenic effects of ELF magnetic fields. Importantly, there is no generally accepted biophysical mechanism that could explain such effects. However, there is increasing evidence that induced genomic instability (IGI) plays a role in environmentally induced cancer. IGI is a concept describing the delayed damage which can be observed many cell generations after exposure in the non-exposed progeny of exposed cells as increased mutation frequency, apoptosis, chromosomal aberrations, micronuclei and other damage. In this presentation a link between the possible carcinogenic effects of ELF magnetic fields (and possibly also of other non-ionizing radiation) and genomic instability will be proposed and discussed.

S11-O2

The health effects derived from UV radiation and sunbed use

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[No abstract available]

S11-O3

Use of non-ionizing radiation in beauty care

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Introduction

Non-ionizing radiation is applied in beauty care in various different ways and for several reasons. Almost full range of non-ionizing radiation is utilized ranging from low frequency electromagnetic fields to radiofrequencies, optical radiation including near-infrared, visible light and ultraviolet radiation. Also appliances utilizing ultrasound are very popular.

As the appliances are getting cheaper and the ways of applying non-ionizing radiation is increasing, it is important to have the latest knowledge on these applications and risks they pose. Legislation does not follow very rapidly this development and product standardization is also lagging behind the innovations created by the beauty care industry. Common trend is that technologies earlier used only by medical professionals have found their ways in the hands of ordinary cosmetologists and even consumers.

Due to the non-harmonized legislation in the field of non-ionizing radiation, countries handle the issue in different ways. The methods discussed in this paper represents the legislative requirements in Finland. European regulation (2017/745) on medical devices has been published in 2017 [1]. It contains a list of groups of products without an intended medical purpose. When the common specifications presented in the regulation are available, harmonization of requirements within Europe is expected for certain types of products.

Electromagnetic fields

Applications

The applications apply radiofrequencies mainly ranging from circa 300 kHz to 10 MHz. The main purpose is to heat the subcutaneous tissue by applying the treatment head directly in contact with the skin. Depending on the frequency and positioning of the electrodes, the depth and extent of the treatment area varies significantly. Also the type of tissue affects how deep the electromagnetic radiation penetrates the tissue. When the treatment head of an radiofrequency appliance is in contact with the skin, the electric current is mainly absorbed by the skin and fat layer. Very small part is absorbed by the muscles. This can be seen from the figure produced by a SEMCAD simulation (Figure 1). The positioning of the electrodes affects the distribution of the electromagnetic field. The manufacturers have produced various shapes and types of treatment heads aiming to affect the tissue layer of interest.

Risks

The energy absorbed by the tissue depends on several factors. If the treatment head is kept in stable position or moved very slowly, it is possible that the tissue heats up too much causing damage to the skin or the subcutaneous tissue. In the latter case the damage may remain non-visible to the eye. If the procedure is carried out carelessly the consequences may be harmful. According to the measurements and simulations carried out at Radiation and Nuclear Safety Authority (STUK), those radiofrequency appliances that do not have a galvanic contact to the skin,

the exposure is significantly lower than with those having galvanic contact. Thus, the use of those appliances is less risky. STUK participates in the development of a safety standard for various beauty care appliances. The aim is that the safety of the use of the appliances is included in the standard.

Legislative requirements

The legislation in Finland applies local specific absorption rate (SAR) to determine whether the use of an radiofrequency appliance is permitted by the law. The exposure limits are based on ICNIRP guidelines [2]. When the Finnish Radiation Act [3] was renewed in 2018, a relaxation regarding the exposure limits was implemented. While it was earlier required that the local SAR do not exceed the limits for general people, the new legislation approved the use of higher local SAR equal to those given for employees. This relaxation is included in STUK order S/5/2018 [4]. The new limits are five times as high as the original limits. Despite this, STUK expects that there are no significant additional risks, if the limits are applied properly and contraindications are applied properly.

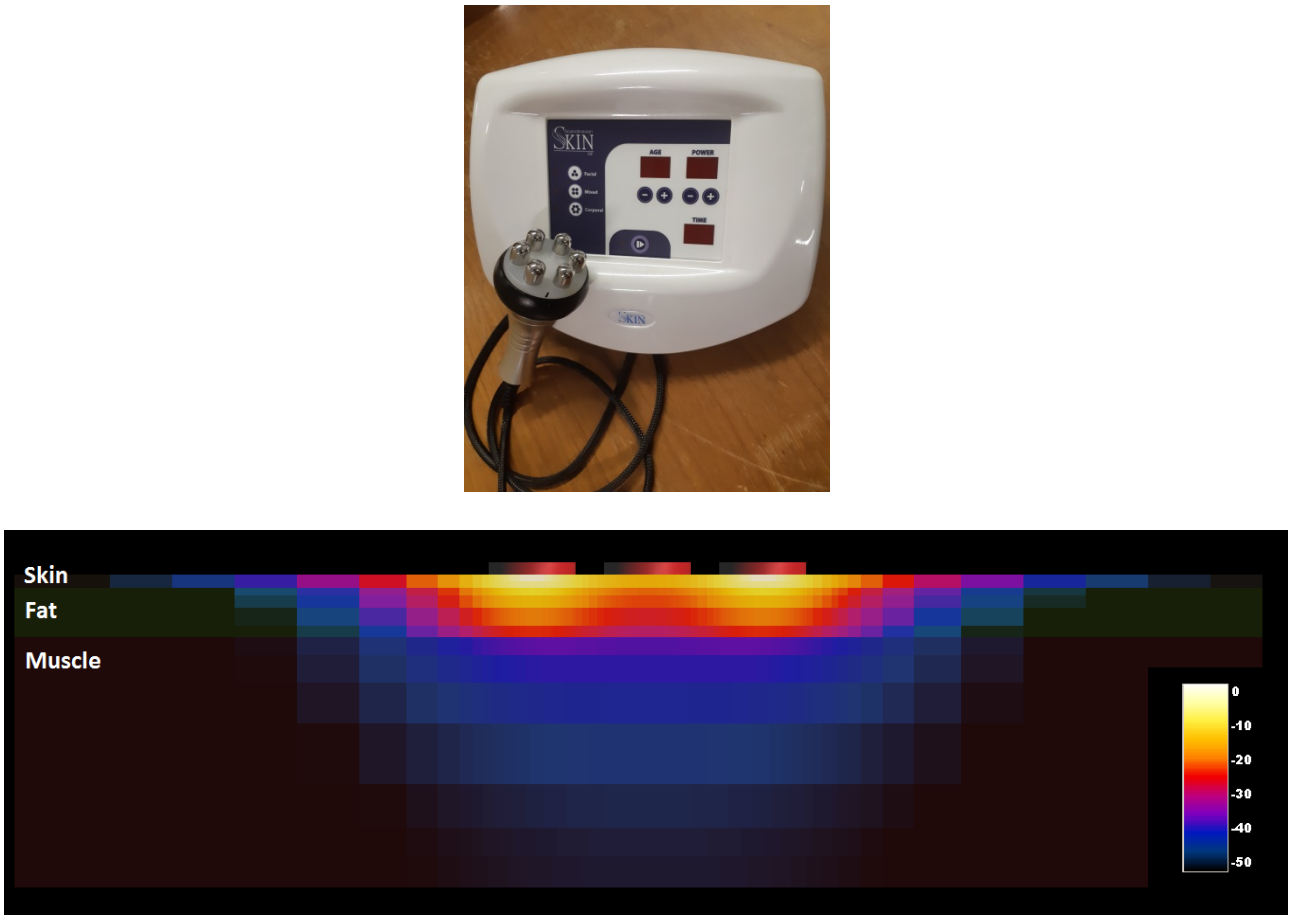

Fig. 1. (Upper) Radiofrequency beauty care appliance. The treatment head has six electrodes with two polarities. (Lower) Distribution of SAR in various tissue layers simulated with SEMCAD X. The areas with highest SAR are shown with the brightest colours.

Optical radiation

Lasers

Lasers produce optical radiation of various intensities, durations and wavelengths. As it has long been known that laser beams may damage the eyes or the skin, a classification system has been

established for them in an international standard IEC 60825-1 and its European version EN 60825-1. The classification mainly concentrates on eye damages, but it can also be used to indicate skin damage probability. The highest class (class 4) is reserved for the most powerful lasers. Although it is not certain that such a device always causes skin damage, the risk increases with increasing intensities. The duration of the laser pulse plays important role as the skin can tolerate certain amount of energy, if it can cool down between pulses. The wavelength of the radiation is important as the skin absorbs and transmits different wavelengths differently. Also the colour of the skin affects the way how the laser beam is absorbed by the skin. Moles, tattoos and other darker pigmented areas are also more susceptible to absorption than pale skin. If the absorption remains superficial, the skin can get damaged as the volume in which the energy is absorbed is smaller than when the beam penetrates into deeper skin and tissue layers or reflects away from the skin.

Intense pulsed light

Intense pulsed light (IPL) is used for example for rapid heating of the hair on the skin or the skin itself. The main purpose in hair removal is to heat up the visible part of the hair in such away that the heat is transferred to the follicle permanently damaging it with excess heat. The operation works best when the skin is pale and the hair is dark as the energy is absorbed by the hair but in lesser extent by the skin. IPL is also used for many skin treatment purposes such as skin rejuvenation, epilation and removal of problems related to pigmentation.

Risks

When optical radiation is applied with short pulses and high intensity, the skin may absorb too much energy causing skin burn. For example tattoo removal is commonly carried out with lasers utilizing various wavelengths in order to shatter the tattoo ink particles into smaller pieces that macrophages can consume thus fading the tattoo. Different wavelengths is used for different ink colours. The use of high intensity laser pulses may cause adverse effects leading for example to permanent scarring of the skin. Intense pulsed light may lead to skin burn, if the energy of the light pulses are too high. Other adverse effects are for example erythema or changes in the pigmentation.

Legislative requirements

In Finland the use of lasers and other optical radiation is regulated by the legislation. Exposure limits given in the decree by the Ministry of Health and Social Affairs (1045/2018) [5] are based on ICNIRP guidelines [6,7]. STUK order S/5/2018 contains additional requirements for the treatments.

Class 4 lasers are always considered to be too effective to be used by ordinary cosmetologists. Therefore those operations shall be carried out in health care units. These units are supervised by the National Supervisory Authority for Welfare and Health (Valvira). Also some class 3B lasers exceeds the exposure limits for the skin, which means that the safety of use of these lasers must be evaluated case by case. The new legislation did present a minor relaxation for continuous wave lasers of class 3B. These are allowed to be applied in beauty care even if the exposure limits for the skin are exceeded. But there are additional terms for the permission, which are stated in the STUK order. Class 1, 1M, 2, 2M and 3R are considered safe for the skin.

Intense pulsed light appliances do usually exceed the exposure limits presented in the decree. However, in the case of those appliances there is a five year transition provision for the application

of the exposure limits. This transition provision was presented due to the fact that there are several appliances in use and no higher exposure limit could not be justified due to lack of proper knowledge regarding the safe use of intense light pulses. The aim is that during this five year transition period international product standards would be published, new recommendations by international expert organizations would be available and the manufacturers would have time to present methods how the safety of the use of the appliances is ensured.

Ultrasound

Applications

There are several ways to apply ultrasound in beauty care. The most common way is to use it for skin cleansing. The ultrasound is transferred to the skin via a metallic spatula that is pressed on the skin. Together with gel, the impurities are removed from the skin when the spatula is vibrating at ultrasound frequencies (circa 40 kHz). This type of use is most likely safe as the intensity is not very high. However, it should be noted that eyes are very sensitive to ultrasound.

Higher intensities of ultrasound are generated in a cavitation process. In this type of treatment relatively low ultrasound frequencies are applied with high intensities capable of producing gas bubbles in tissue. This phenomenon is called cavitation. The intensity is so high the gas bubbles actually bursts or explodes with the aim to damage fat cells. Low frequencies do traverse more deeply in the tissue and are capable of reaching the fetus of a pregnant woman. Due to its violent and risky nature, this type of procedure should be left to the professionals in medical care. Ultrasound may also be used as microfocused ultrasound for skin tightening.

Risks

The main risks associated with ultrasound concentrate on the most effective appliances, which have the intention to damage fat cells or other tissue. For instance in cavitation gas bubbles are generated into fat layer eventually exploding fat cells. The effect may be dramatic and it may be possible that the ultrasound waves affect internal organs or even the fetus of a pregnant woman. The side effects may be very dramatic. High intensity focused ultrasound (HIFU) and microfocused ultrasound (MFU) are commonly used to generate small extremely focused points of ultrasound aiming to damage the subcutaneous tissue deliberately. Although the depth of the focus point is better defined as in the case for cavitation, unintentional damage is possible.

Legislative requirements

Ultrasound was introduced in the Finnish Radiation Act as a new field of non-ionizing radiation. A five year transition provision was given for the exposure limits. Unlike in the case of IPL appliances, the STUK order includes higher exposure limits for ultrasound appliances than those enacted in the decree. The reason is that there is a safety standard for medical physiotherapy appliances that gives a reasonable exposure limit for ultrasound emitting appliances.

Discussion

The renewed Finnish Radiation Act takes better into account the new technologies in the beauty care industry that has emerged. The exposure limits presented in the decree of Ministry for Health and Social Affairs are applied from ICNIRP guidelines. The exposure limits are allowed to be exceeded, if the safety of the operation is ensured. STUK order gives additional requirements for the assessment of safe use. As standards, regulations of the European Union, recommendations of

international expert organizations are still in development, updating of requirements may become necessary within the next years. The current exposure limits takes better into account conditions where the exposure is more controlled than in ordinary situations. Also as the user of the appliance is required to inform the client about the risks associated with the operation and to take into account the relevant contraindications, the safety of the operation is not compromised with higher exposures than those presented in the decree. The manufacturers have been given the possibility to prove that the use of the appliance is safe even that exposure limits presented in STUK orders are exceeded, which can be considered as a major relief. So far, STUK has not received any proposals for evidence of safe use.

Conclusions

The use of non-ionizing radiation is increasing in the field of beauty care. The task of the radiation authorities is to follow this development, ensure the safety of the use and propose new legislative actions if harmful or dangerous applications emerges in the market. The currently renewed Finnish legislation does include several new technologies applied in the beauty care industry. Harmonization of standards and legislation around Europe would improve the safety as the current situation with national legislations may be considered confusing for the manufacturers.

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S11-O4

Sunbed use in Iceland 2004 - 2018

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Sunbed use in Iceland increased rapidly in the 1980s and was about double that of Sweden around 2005. This is thought to have contributed to the high melanoma incidence in Iceland at that time, when Icelandic women had the highest incidence of melanoma in the Nordic countries. Since then, an effort has been made to decrease the use of sunbeds, e.g. by launching campaigns on the dangers of sunbeds and setting an age limit of 18 on sunbed use.

The Icelandic Radiation Safety Authority has conducted surveys on the sunbed use and the number of sunbeds in Iceland from 2004 to 2018.

The survey results showed a clear decrease in the use of sunbeds from 2004-2018: The proportion of the Icelandic adult population that had used a sunbed in the last 12 months dropped from about 30% to 8%. The adult surveys included people of age ≥16y before 2012 and ≥18y in and after 2012. The number of sunbeds in Iceland showed the same trend. From 2005 to 2017, the number of sunbeds in Iceland decreased from 277 to 90 sunbeds or from about 0.9 to 0.3 sunbeds per 1000 inhabitants.

The survey results are a valuable source of information on the sunbed use of the Icelandic population and can be used e.g. to identify the group of people that need to be targeted in campaigns to further decrease sunbed use and for studies on the incidence of melanoma.

S12-O1

Improved radiation safety in Finland with graded approach in the new regulatory framework

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In Finland the previous Radiation Act from 1991 was replaced in 2018 with the new Radiation Act 859/2018. The fundamental idea was that the licensee should assume their roles and responsibilities better with a full scope to the radiation safety commensurate with the radiation risks. The legislation and regulation includes many elements of graded approach, but the most visible example is the categorization of public, occupational and medical exposures into three categories based on radiation risks. The categorization is regulated in details in the Governmental Decree on Ionizing Radiation (1034/2018). The categorization is performed by the licensee and validated by STUK. Moreover, radiation sources, such as use of unsealed sources in laboratories, discharges of radioactive substances, sealed sources and waste to be disposed of in the form of mounding will be categorized.

In the presentation examples are given on categorization of exposures and radiation sources and implications of that for the licensee. Also first experiences in establishing the new system of radiation protection experts and radiation protection officers in Finland. The experiences are described in different categories of exposures. Moreover, preliminary experiences in implementation of graded approach in the regulatory oversight will be shared.

S12-O2

Radon action plan of Finland

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As part of the national implementation of the Basic Safety Standard –Directive (2013/59/Euratom), a Radon Action Plan (RAP) should be prepared in all Member States. That has been included in the Finnish Radiation Act and Governmental Decree on ionizing radiation. The RAP has been drafted by Radiation and Nuclear Safety Authority (STUK). The RAP has been introduced and discussed with stakeholders and will be finalized in 2019. The steering committee of RAP includes representatives of Ministry of Social Affairs and Health (chair and the responsible body), Ministry of Environment, National Supervisory Authority for Welfare and Health, regional health protection authority, regional occupational health authority, the Association of Finnish Local and Regional Authorities, and STUK. The presentation will include the highlights of the RAP, such as long term goals and means of the radon safety, overviews of the national radon database, and recommendations for future work.

S12-O3

Implementing 3S in Practice – Conducting the 3S inspections

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Safety, security and safeguards are taken into account in licensing the use of nuclear materials. It is typical that all these regimes have their own approaches and practical implementation is done separately. However, the co-operation and combination of three Ss during the inspections can prove of primary importance, and also strengthen operators to understand their responsibilities and duties.

In Finland, 3S approach is included in to legislation and regulations for nuclear material users. The licence holders must comply with requirements set both in regulations as well as those set in licence conditions. Before starting operation, safety, security and safeguards shall be taken appropriately care. Therefore, STUK verifies that licensee has necessary arrangements for safeguards and security in place, and operation can be conducted safely. The safety, security and safeguards inspections can be performed together, but can also be focused in smaller entity, such as combination of safeguards and security in the management system of a nuclear power plant.

As an example of 3S inspection in practise, STUK made an inspection to the VTT Centre of Nuclear Safety. In VTT safeguards, security and safety experts performed together the inspection before operation of the facility was approved to start. The experts came from three different departments: Nuclear Waste Regulation and Safeguards, Nuclear Reactor Regulation (security) and Radiation Practices Regulation (safety). This paper describes the preparation, conducting and outcome of 3S inspection by STUK. The objective is to highlight possibilities and advantages as well as challenges of combination of different Ss during inspections.

S12-O4

National best practices: Implementing guide for security arrangements of radiation sources

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Introduction

The new Radiation Act (859/2018) released in 15.12.2018 have influenced to the content of regulations given by the STUK, The Radiation and Nuclear Safety Authority. Due to new regulatory documents, a demand for specific instructions on security arrangements for radiation sources has arisen. This extended abstract focuses on national best practice where regulator publishes a guide to support operators' activities as STUK's strategy 2018-2022 pursues, with theme of coaching supervision.

Purpose

New STUK regulation for security arrangements of radiation sources has been issued by virtue of Radiation Act. Compared to the old regulatory guidance, detailed instructions have been cut from the regulation and only requirements have remained. This have led to a situation, where up-to-date guidance is not available in same extent as during the old Radiation Act.

Change from regulatory guidances to new regulations concerns the whole field of safety and security regulations issued by STUK. To help operators comprehend and function in new regulatory environment, several guides will be published so that especially new requirements can be implemented. The guide for security arrangements of radiation sources will be first of a kind, a prototype for e-guides by STUK.

Radiation safety measures relating to the use of radiation do not always pay sufficient attention to the fact that radiation sources may be subjected to illegal activities; for example, radiation sources may be wilfully harmed or used for harming something else. To cover such cases, radiation safety measures need to be supplemented by special arrangements called security arrangements. The regulation and the guide shall apply to radioactive substances and radiation appliances that contain such substances as well as to mobile devices that produce radiation electrically. The regulation or the guide do not cover security in the transport of radioactive substances and shall not apply to the use of nuclear energy and nuclear materials.

The guide will combine up-to-date regulation, best practices to implementation, experiences and observations from several inspectors, national criteria and international guidelines. The main focus is on how-to -material, examples and explaining each regulation and demands. On top of that, operator's work towards better safety- and security culture and overall corporate security will be emphasized with guidelines and good practices from different fields of security.

Operators' responsibility is one of the main themes of the new Radiation Act and the security guide will take it into account. The guide will talk through STUK's proposal what to do or what not to do, to reach as high level of security as reasonable.

Methods

Development of the guide started as a thesis-work for bachelor studies of security management (Bachelor in Business Administration, Security Sciences). Study was based on literature, interviews and an enquiry. The goal was to find out current state of security of radiation sources and functionality of guidelines towards better security and safety of radiation sources in Finland. Literature review covered the basis of Finnish act, decree and regulations concerning security of radiation sources, STUK's material, operators' material sent to STUK, several guides and researches and studies from field of security sciences. The goal of interviews and enquiry was to get operators' perspective to the study and to help creating an user-friendly guide.

Results and discussion

As a current state of security arrangements of radiation sources in Finland, the study unveiled that the operators apprehend security requirements and implement them in "a punctual Finnish way". Finnish security requirements for radiation sources are more demanding relatively to most countries. For example security requirements concern all mobile x-ray devices whereas some countries apply security requirements only for radioactive material.

According to the study, malicious act towards radiation sources used in industry is not considered likely by the operators. This may lead to fact that security culture, which is hard to measure, determines that either security systems function or are useless. Operators are very diverse, but same legislation and same regulations for security arrangements cover the whole field. Anyhow radiation sources are well secured in Finland, responsible personnel are competent and technical security systems are high quality.

Operators pointed out that lack of resources is biggest threat to functioning security. Fulfilling requirements for technical security systems is expensive

Conclusions

Feedback from the interviewed operators helped creating the guide, especially defining themes and setting up the content best possible way. There was also some contradictions between different operators. On the other hand one operator wanted only bordering themes how to fulfil required security level, and one wanted strict step to step guidance how to fulfill requirements in every scenario. Former is the targeted option, when it comes to creating guide for diverse field of operator having the idea of operator's responsibility on mind.

The regulation of security arrangements of radiation sources doesn't require for example certain level of security culture or performing risk analysis. Promoting and recommending additional components is important though, and taken into consideration in the guide. Without identification of a risks, it is hard to prepare against one. Security-risk aware mentality may be too rarely associated with supporting processes, which use of radiation is, in many cases in industry.

The guide is currently being built to online platform and simultaneously updated and improved. it is set to be released before the NSFS Conference will take place in Hanasaari in June. The First version will be available only in Finnish, but hopefully in near future in English and Swedish as well.

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S12-O5

Methods and challenges of communication in radiation protection

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[No abstract available]

S12-O6

Radon at work places - concentrations during working hours vs. long term average

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Radon concentrations at workplaces are discussed in this presentation. A first screening measurement is typically carried out using an integrating radon measurement of two months. It is an easy and cheap measurement but it often overestimates the radon concentration during working hours if there is a scheduled mechanical ventilation at the workplace. This is due to the fact that mechanical ventilation is operated at higher level during working hours than at other times reducing the radon concentration. Nevertheless, the screening measurement is feasible since with it one can find the workplaces where radon concentration may be greater than the reference level during the working hours. Most of the screening measurements are less than the reference level. Radon concentration during the working hours can be determined with a continuous radon measurement of typically one week.
To compare the results of the integrating and continuous radon measurements, data in the national radon measurement database were utilized. In total of 299 workplace were found with both measurements carried out. About 80 % of the radon concentrations during the working hours were less than the reference value of 400 Bq/m3 although the integrating measurement were greater than that. A detail results of the data analysis will be presented. As a conclusion STUK recommends to carry out the continuous measurement to determine the radon concentration during working hours in the workplaces having a scheduled mechanical ventilation.

S12-O7

Nordic project to establish diagnostic reference levels for paediatric patients

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Introduction

The new European Radiation Protection Directive (2013/59 EURATOM) [1] has reiterated the requirement to establish diagnostic reference levels (DRLs), also for special groups of patients, e.g. paediatric patients.

Establishing DRLs for paediatric patients is particularly difficult due to several factors:

- The large span in patient size from premature babies to teenagers
    - Weight: from less than 1 kg to more than 70 kg
    - Length/Height: from around 50 cm to 180 cm
- The number of examinations is low
    - Children constitute only around 20 % of the population
    - Lower number of examinations per person for children than for adults

For relatively small countries like the Nordic countries, it is beneficial to cooperate with other countries to gather the sufficient amount of data to establish DRLs for paediatric examinations within a shorter time.

As a result of the PiDRL project (European Diagnostic Reference Levels for Paediatric Imaging), the European Commission has recently published guidelines on setting DRLs for paediatric patients in the document 'European Guidelines on DRLs for Paediatric Imaging' [2]. These guidelines are based on the principles in the recent ICRP publication on DRLs [3].

Methods

In an effort to speed up the process of establishing DRLs for paediatric patients, The Nordic Group on Medical Applications (NGMA) have initiated a project to collect data for patient doses for paediatric x-ray examinations. Finland have recently set their own DRLs, so they decided not to be part of the data collection, but the Finnish DRL values can be used for comparison. Thus, hospitals in Denmark, Iceland, Norway, and Sweden participated in the data collection.

It was decided to collect data based on indications, where relevant, and not only on type of examinations, as recommended in recent guidelines [2, 3]. Decision on which examinations and indications to include in the data collection were based on the PiDRL guidelines [2] and on the expected total numbers of different examinations, after consultations with reference groups of radiologists and radiographers in the individual countries. The numbers of examinations for selected common examination types in the Nordic countries are shown in tables 1 and 2. Numbers

from Denmark, Finland and Iceland are from national registries, while the numbers from Norway and Sweden are estimates. Where a cell is left blank, the number is unknown.

Table 1. Number of examinations per year for paediatric patients for selected conventional radiology and fluoroscopy examinations.

Conventional	Denmark	Finland	Iceland	Norway	Sweden	Estimated total
Chest	19.327	53.393	1.964		36.500	110.000
Lumbar spine	2.325	2.277	43		2.300	6.900
Scoliosis	3.376	4.289	41	5.000	1.900	9.600
Pelvis, hip joints	5.574	3.943	438		6.000	16.000
Small intestine passage	277	299	124		1.700	2.400
MCU	251	290	30		900	1.400
Abdomen	3.512	1.492	388		7.800	13.000

Table 2. Number of examinations per year for paediatric patients for selected CT examinations.

CT	Denmark	Finland	Iceland	Sweden	Estimated total
Head	1.542	1.415	220	10.200	13.400
Adomen, pelvis	413	184	83	1.500	2.200
Spine	1.460	847	32	1.300	3.600
Joints/soft tissue	0	100	33	1.275	1.400
Chest	546	509	84	1.040	2.200
Trauma	302	139		810	1.300
Hip joints	46	45	16	310	400
Urinary track	74	29		80	200

In order to best assure that a sufficient number of data sets would be achieved within a reasonable period of time, the estimated total numbers of examinations were taken into account when choosing the types of examinations to include. It was also considered including interventional radiology, but the number of examinations was even lower than for the examinations shown in the tables. Finally, the following examinations and clinical indications were included in the data collection:

<u>Conventional radiology/fluoroscopy:</u>

- Abdomen; overview
- Chest (lying, sitting or standing)
- Lumbar spine
- Pelvis, Hip joints; e.g. pain
- Pelvis; e.g. dysplasia or metastases
- Scoliosis; primary and follow-up

<u>CT:</u>

- Abdomen with contrast; tumour or inflammation
- Brain; infarct or bleeding
- Brain; ventricular size/shunt
- HRCT of lungs;
- Lungs with contrast; tumour
- Trauma (head, thorax, abdomen); High energy trauma

Doses were collected for patients up to 15 years of age; for children less than 4 years old, the age was recorded in months. Additionally, the gender, length/height and weight of each patient was recorded. For conventional examinations, doses were recorded in terms of Kerma air product (KAP), and additionally, the number of images was recorded. For CT examinations, $CTDI_{vol}$ and DLP were recorded. In addition, information on the kind of equipment used as well as essential parameters about the protocols was collected. Data was collected in a number of hospitals in each country, and finally all data was collected into the Swedish Web portal DosReg [4] provided by the Swedish Radiation Safety Authority.

Based on the estimated total number of the different types of examinations, it was deemed possible to get a sufficient amount of data sets from the chosen conventional and CT examinations within a six months project period, from March – August 2018. However, it turned out that the reporting rate for some of the examinations was not high enough to get the excepted amount of data, and the period was extended to 1 year, until Medio March 2019.

Where possible, the data will be used to provide DRL curves, i.e. curves of DRL values as a function of the weight of the patient. The 75 % percentile will be used as the DRL value, while the 50 % percentile (median) will be reported as an achievable dose level. If insufficient data is available to provide for DRL curves, values will be provided for different groups of patients, following the recommendations from PiDRL, se table 3.

Table 3. Recommended grouping of patients for paediatric DRLs [3].

Recommended weight groups (intervals) for *body* examinations	Recommended age groups (intervals) for *head* examinations
< 5 kg	< 3 months
≥ 5 kg, < 15 kg	≥ 3 months, < 1 year
≥ 15 kg, < 30 kg	≥ 1 year, < 6 years
≥ 30 kg, < 50 kg	≥ 6 years
≥ 50 kg, < 80 kg	

Results

Even with the extended data collection period, for some types of examinations, a smaller than expected number of data points was obtained. The number of patients for which data has been reported is shown in tables 4 and 5 (next page) for conventional and CT examinations, respectively. The tables shows the total number of data points for each examination type together with the number for each of the two age groups: 0-48 months and 4-15 years.

Initial analysis of the data has shown that the necessary confidence in the results of the analysis can be achieved where at least 200 data points has been obtained. This has been achieved for about one third of the examinations included, and it has been decided at the moment to limit further analysis to these types of examinations. The types of examinations where the number of data points are too low for further analysis at this point have been marked with italics in tables 4 and 5.

Table 4. Number of patients for which data has been collected for conventional examinations.

	0-48 months	4-15 years	Total
Abdomen	66	150	216
Pelvis / hip joints	*128*		*128*
Lumbar spine	*3*	*44*	*47*
Chest, bed	221	11	232
Chest, standing	310	453	763
Pelvis	99	144	243
Scoliosis, primary	*2*	*153*	*155*
Scoliosis, follow-up	*4*	*77*	*81*

Table 5. Number of patients for which data has been collected for CT examinations.

	0-48 months	4-15 years	Total
Abdomen with contrast	12	212	224
Brain; infarct or bleeding	391	876	1267
Brain; ventricular size/shunt	*16*	*41*	*57*
HRCT	*19*	*67*	*86*
Thorax with contrast	*39*	*82*	*121*
Trauma	*1*	*26*	*27*

For some examinations, especially some conventional examinations, there was a very large spread in the reported data between different hospitals. It is suspected that this could, at least in part, be due to errors in the unit of KAP used. Consequently, a data cleaning process has been initiated, where selected hospitals are contacted to check that their data has actually been measured in the reported units.

Preliminary conclusions

It is expected that it will be possible to set recommended DRLs for the following paediatric examinations. For CT examinations, indications are included:

- Abdomen
- Pelvis
- Lungs, standing and bed
- CT abdomen with contrast; tumour or inflammation
- CT Brain; infarct or bleeding

DRLs will primarily be provided as DRL curves.

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S12-O8

Collecting relative frequencies and assessing radiation doses of pediatric radiology procedures involving ionizing radiation: Data collection methods and first results.

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Abstract
The presented study aims to collect technical parameters from a representative collection of radiological examinations and interventions in pediatric radiology. Results will be used to establish new Diagnostic Reference Levels (DRL) in pediatric radiology.
As a first step, hospitals, private practices and non-specialized institutes conducting radiological examinations had been identified and asked for participation in a questionnaire. The purpose of the questionnaire was to identify institutions with at least 20 examinations in typical pediatric procedures in children under the age of 16 years. The goal was to include a sample of 50 such institutions. The data collection is carried out in two successive steps: First, the relative frequencies of pediatric examinations are collected and in a second step, the technical examination parameter for selected standard examinations are collected and processed. The data can be provided by the participants based on exports from a Dose Archiving and Communication System (DACS) or Dose Monitoring System (DMS), from a Picture Archiving and Communication System (PACS), from a Radiological Information System (RIS) and using a manual Excel file-based approach. While providing data from a DACS/DMS is straightforward, we developed a new software solution to collect the data from PACS systems.
This talk will discuss the used methods in detail and reports first results. We will also share our experiences and difficulties in implementing the project. This project is financed by the Federal Office for Radiation Protection (BfS), Germany.

Introduction
Medical procedures are the biggest contributor to exposure to ionizing radiation from non-natural sources. In Germany, the average annual effective dose due to medical exposure is about 2 mSv [1]. Paediatric patients represent a group with a high radio sensitivity [2], and several studies have reported a higher risk of cancer due to CT examinations [3-6].
Application of the ALARA principle to optimize radiation dose is thus especially important in paediatric radiology [7]. This task is challenging as indications change over time and pediatric patients are grouped in different age and weight groups [8].

Purpose
The focus of this study is first the recording of frequencies of radiological examinations in pediatric patients, in order to identify the most common examination types. Second, technical examination parameters are collected that will allow the assessment of the implementation of the different examination types and the definition of new Diagnostic Reference Levels (DRLs).

Methods

The project is run in three successive steps that are addressed in the next sections:

Step 1: Identification of participating institutions.

To reach the study goal of 50 participating relevant institutions, we approached the relevant professional societies (German Radiological Society (DRG), Society of Pediatric Radiology (GPR) and German Society for Interventional Radiology (DeGIR)) with an invitation to participate in an online questionnaire. The focus of this questionnaire was to (a) evaluate the frequency of pediatric radiology procedures in each institution, (b) the way data can be provided and (c) the willingness to participate in further data collection.

Step 2: Collection of relative frequencies

The examination frequencies could be provided (a) from a Dose Management System (DMS), (b) from the Radiology Information System (RIS), (c) from Picture Achieving and Communication System (PACS) using a dedicated software tool and (d) manual from other sources.

The data was then used to select the most common examinations in Germany and identify a set of examinations for step 3, the collection of technical examination parameters.

Step 3: Collection of technical examination parameters of selected pediatric radiology procedures

In the final data collection, we collected retrospectivly for a period of two years, the technical examination parameters from the selected examination types.

We used the export from a DMS, if available, and the PACSQueryTool otherwise. This custom developed software tool collects for a given time period and for given study descriptions/series descriptions of all performed studies from the PACS and stores the needed technical examination parameters in a local database. This is done using a standard QUERY / RETRIEVE DICOM connection to the local PACS. The frequency collection (step 2) can be performed rather fast, as only simple, split DICOM Query request are send. The collection of the technical examination parameters (step 3) takes longer, as this involves an additional retrieve / transfer to the real image. Once data collection is finished, the anonymous data is reviewed by the local staff and uploaded to the secured study cloud.

Another software was developed that assigns the identified standard examinations in step 2 to the local study/series description using lexical text matting. This mapping file was then used as additional input for the PACSQueryTool.

Results and discussion

We invited in (step 1) all members of the relevant professional societies, used personal contacts and identified institutions via Internet search using personal letter or e-mail. Until 19.3.2018 the survey was called 257 times and completely answered 71 times. It was surprising that only about 22 % (12 out of 55) of the institutions can provide the data using a DMS. Some institutions could not use their DMS, as the DMS was only recently introduced.

The data collection of the frequencies (step 2) resulted in 2 236 309 cases. Selected results of the examination frequencies will be shown during the conference talk. The most frequent examination types are shown in table 1 and might act as candidates for new DRLs in Germany.

Existing peadiatric DRLs		Candidates for new DRLs	
XRAY:	Head AP and LAT	XRAY:	Cervical Spine AP and LAT
	Thorax AP/PA and LAT		Lung
	Abdomen AP/PA		Hand/Carpal
	Pelvis AP/PA	CT:	Knee
CT:	Head		Hand
	Thorax		Cervical Spine
	Abdomen		Total Body
Fluoroscopy:			Sinus
	MCU	Fluoroscopy:	
			Esophagus
		Interventional:	
			vessel malformation
			intracardiac catheter

Table 1. Existing DRLs and Candidates for new DRLs in Germany based on their frequency

In the ongoing collection of technical examination parameters (step 3), 7 institutions have already finished the data collection. Data collection continues, and values reported in this paper are only preliminary results.
We observed already in this limited data differences to the established DRLs. As an example, the dose values reported for the "CT Thorax" standard examination are shown for the different age groups in table 2. The shown 3rd quartile for the age group 10-14 years is with a CTDIvol of 2.8 mGy and a DLP of 110 mGy*cm significantly lower than the corresponding DRL [9] of 6.5 mGy and 200 mGy*cm respectively.

Age group [year]	CTDIvol [mGy]	DLP [mGy*cm]	Exposure [mAs]	Total Number
0-1m	0.4	6.0	112.0	71
1m-4y	0.7	21.0	329.0	504
4-10y	1.4	46.0	394.0	350
10-14y	2.8	110.0	613.2	281
14-18y	3.2	190.5	803.8	400

Table 2:; Examination "CT Thorax" 3.quartile

Conclusions

Examination frequencies as well as technical examination parameters can be collected from different hospital IT systems without bigger technical problems. Sometimes it is difficult for participating hospitals to find the needed personnel / time resources.

Currently, DMS systems are entering the institutions, but are not available all over the country. For all evaluations, it is essential that the different examination types are grouped to the same "standard procedure" to do good comparisons. We found the study and series descriptions, that we used to map the individual to a standard examination heterogeneous and sometimes difficult to handle. A more standard naming in the clinical application (RadLex, Playbook,…) will improve this.

First results indicate that the existing DRLs be changed to lower values.

Acknowledgements

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S12-O9

Comparison of eye lens doses measured at the forehead and at collar level

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Abstract

The new lower dose limit for the lens of the eye of 20 mSv per year has been set in force in Denmark from February 2018. The Danish order requires occupationally exposed workers who are liable to receive more than 6 mSv per year to the lens of the eye to be individually monitored with a personal dosemeter that is exchanged once per month.

From 2014, a pilot measurement project on measuring eye lens doses has been carried out in selected departments on a voluntary basis. Mainly medical staff involved in interventional radiology and cardiology procedures participated as it was suspected that this group would receive the highest doses. Each participating person was wearing one dosemeter (single TLD element) at the forehead and one (normal whole body dosemeter) at the collar level.

It was found that the dose measured at the forehead is lower than twice the dose at the collar level in more than 95 percent of the cases, and for the remaining 5 percent the deviation is almost insignificant. It is concluded that the dose measured at the collar level can be used as the basis for a first estimation of the dose to the lens of the eye, and for assessment of the need for further radiation protection measures, e.g. increased shielding or more detailed measurements.
This paper will include results from the pilot measurement project and from ongoing routine monitoring.

Introduction

In the literature[1,2] it is recommended to have the dosemeter for estimating the dose to the lens of the eye placed close to the eye. But also a dosemeter placed at the collar level is suggested to be sufficient in certain circumstances. The personal dosimetry service at SIS is accredited by the Danish accreditation body, DANAK, for use of its whole body dosemeter to measure Hp(10) and Hp(0.07). This whole body dosemeter have also been tested for measuring Hp(3) according to the specification in the DS/EN 62387 standard[3] on the water slab phantom. Only recently, ISO have published a standard on how to calibrate a personal dosemeter for measurement of Hp(3) as an estimate of the dose to the lens of the eye[4]. However for calibration of the dosemeters the impact form use of different phantoms is small if the right radiation qualities are used[5].
The purpose of this project was to see if the doses measured at the collar level in routine conditions correlates with a more correct measure of Hp(3). To measure the later a dosemeter from the personal dosimetry laboratory at Public Health England, PHE, also calibrated to measure Hp(3) was used. The comparison took place from 2014 to 2018.

Methods

Several departments have shown interest in participating in the comparison. They cover several different practices in the medical field, though participation have been on a voluntary basis. All departments participating were instructed to wear the two dosemeters at the same time, and that PHE dosemeter should be placed at the forehead and the SIS dosemeter at the collar level and outside any personal protective apron. There was no restriction on the length of measuring period, but the most frequently used was one month.

Results and discussion

A total of 23 departments located at 10 different hospitals from almost all parts of Denmark took part in the comparison, where 8 different types of practices were carried out: Angiography, Cardiology, CT-guided intervention, Endoscopy, Neuro radiology, Nuclear Medicine, Surgery and Urology. Data for 231 occupational exposed workers were collected, with professions of doctors, nurses and radiographers.

The data are shown in figure 1. It can be seen that the dosemeter worn on the collar level generally overestimates the dose compared to the dosemeter worn at the forehead, i.e. they are on the right side of the red line. This is the case for 59 % of the measurements. It is also clear that though a few measurements show high doses, the highest measured on the forehead of 7.6 mSv, most doses are much lower. 93 % of the doses measured at the forehead are lower than 1 mSv and 62 % lower than 0.1 mSv.

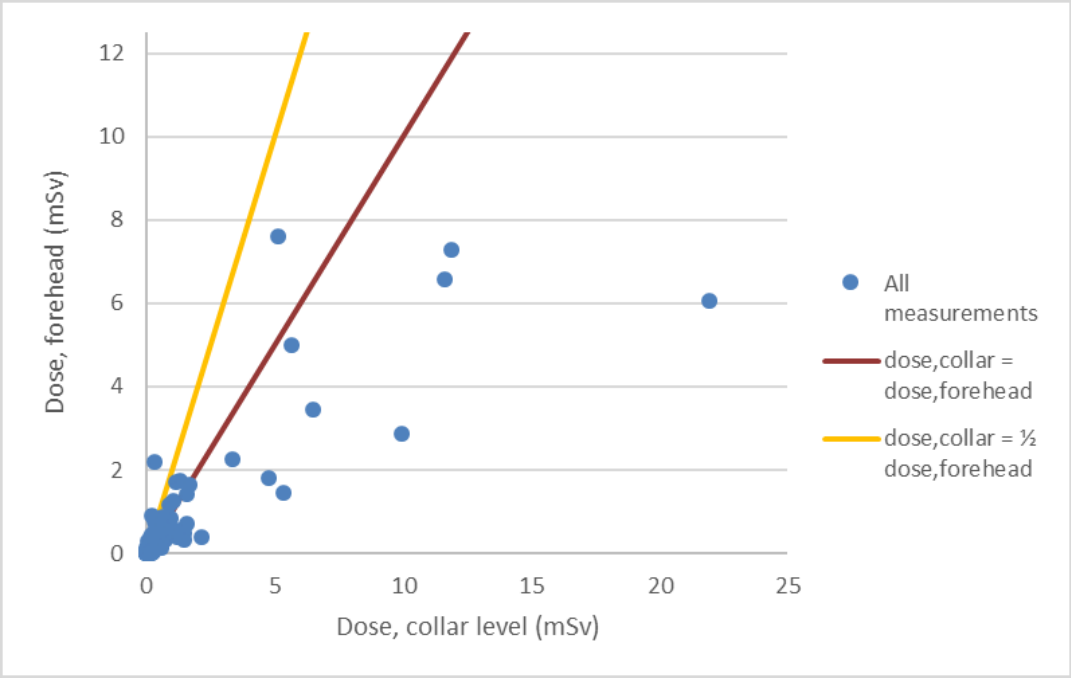

Fig. 1. All 231 individual dose measurements of $H_p(3)$ measured with the PHE dosimeter placed at the forehead and the SIS whole body dosemeter placed at the collar level.

Looking at the data on the right of the yellow line, which corresponds to the dose measured at the forehead equal to twice the dose measured at the collar level, one finds that 95 % percent of the data point are located here. In addition, the highest doses are all on the right side of the yellow line, only one point with a dose at the forehead above 1 mSv and no point with a dose on the

collar level above 0.5 mSv is on the left side. This indicated that 2 times the measured dose, measured at the collar level could be used as a guidance value for whether the dose limit for the lens of the eye is likely to be exceeded or not.

From figure 2 and 3 it can be seen that the workers receiving the highest doses are doctors involved in Angiography procedures.

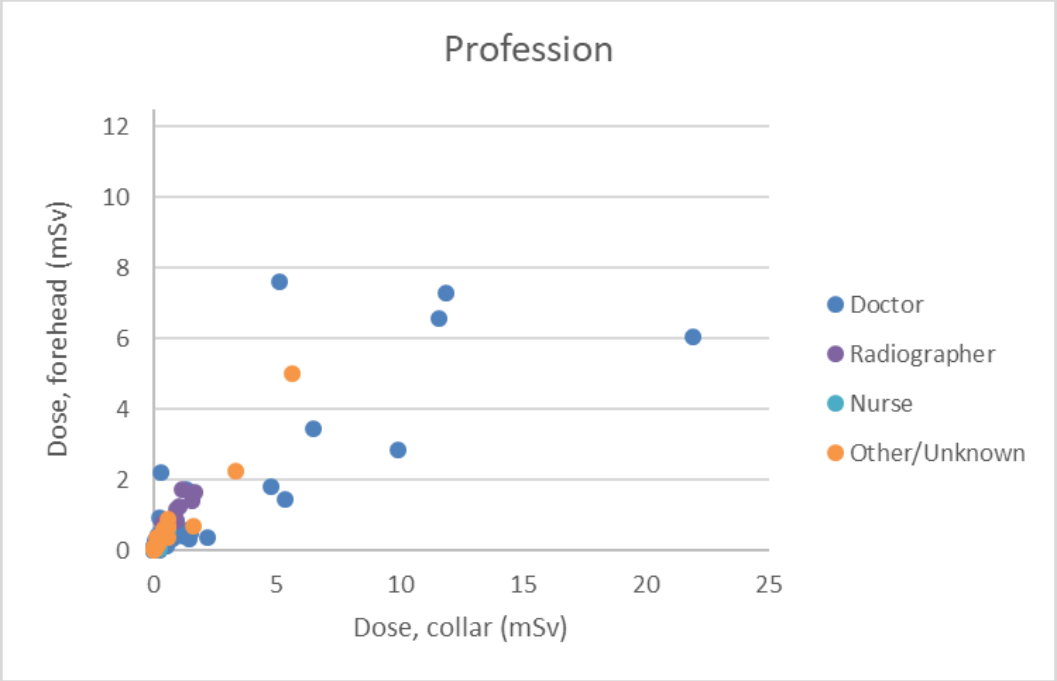

Fig. 2. All 231 individual dose measurements of $H_p(3)$ measured with the PHE dosimeter placed at the forehead and the SIS whole body dosemeter placed at the collar level with indication of the profession of the exposed worker.

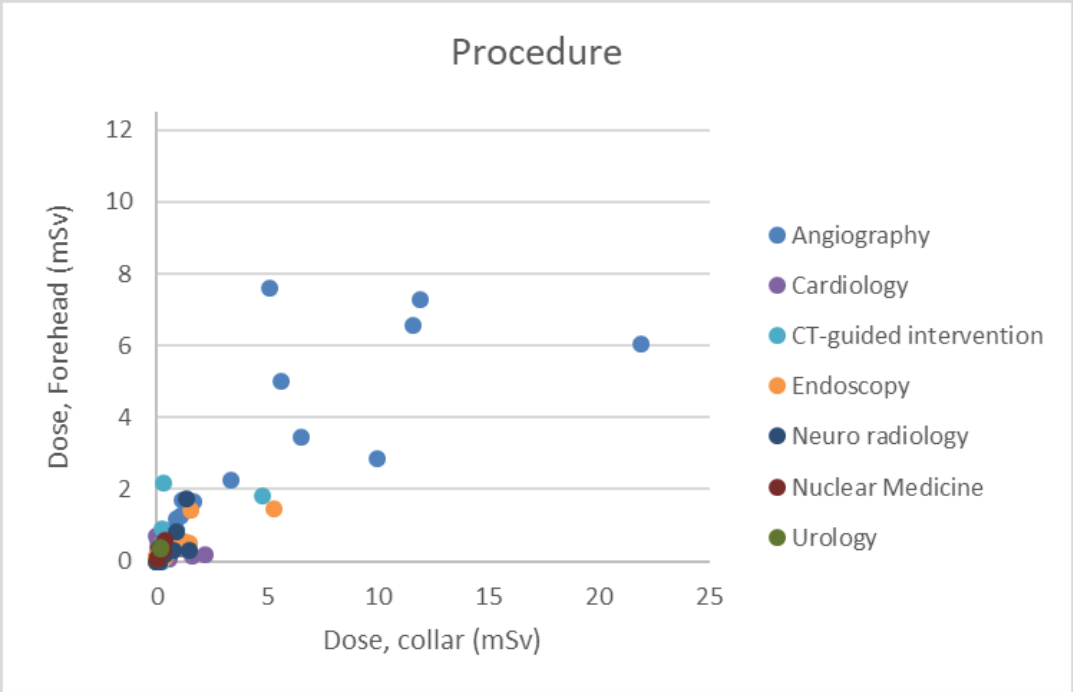

Fig. 3. All 231 individual dose measurements of $H_p(3)$ measured with the PHE dosimeter placed at the forehead and the SIS whole body dosemeter placed at the collar level with indication of the procedure the exposed worker performed

Since 1 September 2018 extra whole body dosemeters to be worn at the collar level have been used routinely for measuring the dose to the lens of the eye, i.e. Hp(3), with a wearing period of one month. They are referred to as 'shoulder dosemeters' to distinguish them from 'normal' whole body dosemeters, as they look alike except for the printing on the dosemeter. Table 1 and 2 shows data drawn from the Danish Register for Personal Dosimetry for the eye lens dose. A total of 38 workers have been monitored until now, and a total of 125 individual dosemeters read out. The data also show that the doctors receive the highest doses and that these are obtained in Interventional Radiology. A yearly dose limit of 20 mSv corresponds to a monthly limit of 1.7 mSv. From the average and median values, it is clear that the majority of the exposed workers are well below the limit. However, it is also clear that some workers might be close to the limit or maybe even likely to exceed this.

Table 1. Average, median and maximum dose to the lens of the eye, $H_p(3)$, in one month measured with the shoulder dosemeter for different professions.

Profession	No. of workers monitored	Average dose $H_p(3)$ (mSv)	Median dose $H_p(3)$ (mSv)	Maximum dose $H_p(3)$ (mSv)
Doctor	24	0,48	0,23	6,7
Nurse	12	0,26	0,10	1,0
Other	2	0,00	0,00	0,0

Table 2. Average, median and maximum dose to the lens of the eye, $H_p(3)$, in one month measured with the shoulder dosemeter for different practices.

Practice	No. of workers monitored	Average dose $H_p(3)$ (mSv)	Median dose $H_p(3)$ (mSv)	Maximum dose $H_p(3)$ (mSv)
Interventional Radiology	30	0,48	0,18	6,7
Surgery	4	0,34	0,22	1,4
Other	4	0,31	0,10	1,3

Conclusions

Generally, the dose to the lens of the eye for occupationally exposed workers in Denmark is low, well below the dose limit. The study also indicates that doctors, especially those involved in angiography procedures, receive the highest doses. As stated earlier, a whole body dosemeter worn at the collar level outside any personal protective apron can be used as an investigation tool on whether the dose limit is likely to be exceeded. Both the comparison and the routine monitoring shows that only for a few workers there is a need for special follow up.

Acknowledgements

We wish to thank all departments and staff participating in this comparison for their time and effort put into this project.

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S12-O10

Lowered dose limit to the lens of the eye- Results from 2018 at Forsmark NPP

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Introduction

Due to statement and recommendation of ICRP, a lower dose limit regarding equivalent dose to the lens of the eye was introduced in both IAEA and EU Basic Safety Standards. The limit was lowered from 150 mSv/year to 20 mSv/year. Considering this new dose limit the Swedish nuclear facilities identified a need to monitor workers´ eye lens doses in order to ensure compliance. Nuclear facilities in Sweden, in cooperation, identified specific works tasks where extra monitoring of the eye was needed. These were situations where the eye is more exposed than the rest of the body due to shielding or where the eye is closer to the source of radiation than the rest of the body.

During 2018 Forsmark NPP identified and monitored several different work tasks and the result is presented in this report. The monitoring is limited by the actual work performed during the time period. Registration of the doses from 2018 will be registered retroactive during 2019.

The results have indicated that nuclear facilities in Sweden need to continue to monitor workers, especially itinerant workers. For correct measurements and analysis, it is important to continue to identify risk tasks in the facilities, assign dosimeters to the right individuals and make sure workers wear the dosimeters in a correct manner.

Purpose

To present the results from measurement performed during 2018 of dose to the lens of the eye.

Methods

Dosimeter

For measurement of equivalent dose to the eye Forsmark NPP uses dosimeters from Public Health England Personal Dosimetry Service (PHE PDS). The dosimetry element is of the Harshaw EXTRATM type, and is enclosed behind a 1.5 mm PTFE filter in a sealed PVC pocket. The headband is fastened by means of VelcroTM strips which can be trimmed to length. The headband dosimeter measures $H_p(3)$. The dosimeter was carried during one month or during specific work tasks, together with ordinary whole body dosimeter (passive and electronic). The background dose was subtracted from all measurements.

Identified specific work tasks

- Service of Control Rod Drive Mechanisms (CDRM)
- Decontamination work on reactor main circulation pump impeller, but also decontamination workers continuously
- Main entrance into reactor main circulation system
- Work on the reactor vessel head
- Other specific work task were the individual dose is estimated exceed 1 mSv

Results

During 2018, 229 measurements were conducted, of which116 measurements resulted in a dose higher than 0.5 mSv, and 69 measurements showed a higher dose to the eye than the effective dose. Presented in this paper is a brief summary of the results from some of the specific work groups.

Decontamination Station

Personnel working in the Decontamination Station were identified as a work force in risk of high eye dose since they have a high dose load during the whole year. They handle material for decontamination from all three units at Forsmark.

The result is based on five individuals with continuous measurements from May to December, total of 40 measurements. 17 of 40 measurements showed $H_p(3) > H_p(10)$, 22 measurements ≥ 0.5 mSv. Maximum identified $H_p(3)$ during the period was 2.4 mSv, compared to $H_p(10)$: 2.0 mSv.

Control Rod Drive Mechanisms (CDRM)

Work on CDRM was early in the investigation identified as a risk work task due to high dose work. 11 of 17 measurement showed a higher $H_p(3)$ compared to $H_p(10)$. Maximum identified $H_p(3)$ during the period was 6.8 mSv, compared to $H_p(10)$: 3.9 mSv.

Insulation personnel

Personnel performing insulation work were identified as a possible work force exposed to non-homogenous radiation fields and possible dose to the eye. Of the 16 measurements performed in 2018, five showed a higher $H_p(3)$ compared to $H_p(10)$. Maximum identified $H_p(3)$ during the period was 1.8 mSv, compared to $H_p(10)$: 1.4 mSv. The dose was received during on and off insulation of residual heat removal system (RHR) and reactor water clean up system (RWCU).

Mechanical maintenance

Three of 26 measurements showed a higher $H_p(3)$ compared to $H_p(10)$. Maximum identified $H_p(3)$ during the period was 7.7 mSv, compared to $H_p(10)$: 5.6 mSv, dose received during service of a valve in the RWCU system.

Non-destructive testing (NDT)

Three of 8 measurements showed a higher $H_p(3)$ compared to $H_p(10)$. Maximum identified $H_p(3)$ during the period was 1.5 mSv, compared to $H_p(10)$: 1.3 mSv.

Industrial cleaning personnel

Four of 32 measurements showed a higher $H_p(3)$ compared to $H_p(10)$. Maximum identified $H_p(3)$ during the period was 1.9 mSv, compared to $H_p(10)$: 1.9 mSv.

Radiation protection

One of 16 measurements showed a higher $H_p(3)$ compared to $H_p(10)$. Maximum identified $H_p(3)$ during the period was 0.7 mSv, compared to $H_p(10)$: 0.9 mSv.

Foreign Material Exclusion (FME)

All performed measurements showed a lower $H_p(3)$ compared to $H_p(10)$. Maximum identified $H_p(3)$ during the period was 0.1 mSv, compared to $H_p(10)$: 0.2 mSv.

Conclusions

The results from the measurements in 2018 have indicated that nuclear facilities in Sweden need to continue to monitor workers, especially itinerant workers. Data from work on CRDM showed a high tendency for a higher dose to the eye than the effective dose, one worker received an eye dose of 6.7 mSv compared to the effective dose ($H_p(10)$) of 3.9 mSv. These jobs are often performed by itinerant workers travelling around NPPs to do the same type of work tasks. Our result implies the importance of correct monitoring and registration between NPPs to keep track of the dose to the lens of the eye.

For other work groups there was little or no difference between the dose from $H_p(3)$ compared to $H_p(10)$ measurements. This shows that it is important to continue identifying risk task in the facility and investigate different work forces in risk of higher dose to the lens of the eye than the effective dose.
We also identified that for correct measurements and analysis it is essential to assign the dosimeters to the right individuals and make sure the worker wears the dosimeter in a correct manner. Identifying the right individual means assigning the dosimeter to the worker standing closest to the radiation source so that the correct dose from the estimated work can be evaluated. Experiences from 2018 report the difficulty in wearing the dosimeter in the correct manner. The head band can be uncomfortable which may lead to misusage. For example contamination by dirty gloves or placing the head band close to a radiation source during redressing or stop work have been identified as a potential source for over or under estimation of the dose.
For the continued work during 2019, two focus areas have been identified: Routines for assigning dosimeter, and handling and carrying of the dosimeters.
By informing the workers on the results from 2018 Forsmark NPP hope to achieve a higher understanding on the importance of correct handling and carrying of the eye dosimeters. The routine for assigning the dosimeters needs to be improved to facilitate communication between worker and the dosimetry personnel.

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S12-O11

Global Cooperation in Radiation Protection - case Saudi Arabia

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The safety use of radiation is our common goal. The purpose of radiation protection is protecting people, society, the environment as well as future generations from the harmful effects of radiation. This is also the mission of Finnish Radiation and Safety Authority, STUK.

Successful regulatory body has a number of responsibilities related to radiation safety of the public and environment and occupational safety. Execution of all of these issues need relevant preparation of the legal base, preparation of regulations, organization with skilled experts and continuous training of them, internal rules and procedures in the regulatory body and well managed international cooperation. All this has been developing in Finland since first Radiation Act in 1957.

The use of ionizing radiation in energy production, industry, medicine and research brings enormous benefits to people – but only if it is used safely. Radiation has no borders like States. Lot of global cooperation is needed to get a radiation safe world. The regulatory work in Finland has been developed more than 60 years and this experience is worth to be shared and exploited. The objective is to introduce jointly reached goals on the development of Saudi Arabia regulatory framework from radiation protection point of view when following the motto: ”Towards a safer world through better understanding, policy and practice”.

S12-P1

Diagnostic reference levels (DRL) in Norway 2017: Results, revision and establishment of new DRL

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New Norwegian national diagnostic reference values in radiology and intervention are based on collected local diagnostic reference doses (LDRL) from 31 health care enterprises (HCE) in Norway. The collection was conducted in March-December 2017. The HCE reported doses for seven conventional studies, 11 CT and six interventional procedures. All studies were indicated by the Norwegian classification of radiological procedures (NCRP) and CT studies were also indicated by a clinical indication. To simplify the collection, two different methods were given to collect the LDRD. 1) minimum 20 patients weighting between 55 and 90 kg for each laboratory, or 2) at least 50 patients from each laboratory regardless of weight. Data for the four cardiological interventional procedures were obtained directly from the Norwegian Registry of Invasive Cardiology.

A total of 564 LDRD for conventional X-ray examinations, 749 for CT and 111 for interventional procedures were reported. For five conventional, five CT and coronary angiography procedures, there were previous national DRL.

Previous established national DRL (2008/2009) were only related to anatomical regions. The current national DRL are based on clinical indications, consistent with international recommendations. DRL based on clinical indications provide a better basis for comparison and optimization than reference values associated with anatomical region. This may be especially important for CT procedures where clinical indications are determinative for how the procedures are performed. For some procedures it was difficult to set the national reference values, either due to few procedures or that the procedures were not completely comparable.

S12-P2

Development of national diagnostic references levels for CT in Denmark

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Recent recommendations from ICRP and the European Commission have stressed that diagnostic reference levels (DRLs) should be given for specific examination types, i.e. based on clinical indication and not only on anatomical areas, especially for CT examinations.

In Denmark, the National Health Authority, Radiation Protection SIS published the first guideline for collection and comparison of doses from CT examinations based on clinical indications instead of just anatomical areas in 2012. With the aim of establishing national DRLs, SIS have carried out two rounds of collection of patient doses for CT examinations on adult patients based on this guideline, the last one in 2018.

The current Danish DRLs for CT examinations on adult patients are from 2015, and new DRLs will be established upon completion of the data analysis of the data collected in 2018. We know that the two recent rounds of collection of patient doses for CT have strengthened the focus on optimisation of CT protocols, and it is interesting to see how this reflects in the measured patient doses and resulting DRL values.

In the poster, selected results from the data collection will be presented, especially trends for DRLs for different examinations as well as for the spread in reported doses.

S12-P3

Assesment of DRLs for PET/CT examinations in the Russian federation

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The aim of the current study was to determine diagnostic reference levels (DRLs) for PET imaging in the Russian Federation. The study included data collection on 27 PET/CT scanners in 10 PET departments and 9 PET centers, in 12 regions of Russia in 2012-2017, corresponding to more than 60% of all PET scanners in Russia. Two main quantities were considered for the establishment of DRLs for PET/CT examinations: administered activities of radiopharmaceutical and DLP for internal and external exposure, respectively. In addition, effective dose was selected as a third quantity for establishing DRLs for PET/CT examinations. The patient doses from hybrid PET/CT examinations were determined as the sum of the effective doses from internal and external exposure. For each PET/CT scanner the effective dose from internal exposure was estimated using conversion coefficients from ICPR (Pub. 128), for typical administered activities. The effective dose from external exposure was calculated using XXXX software and tissue weighting coefficients from ICRP (Pub. 60). The 75th percentiles of dose distribution were selected as the preliminary values for the national DRLs.

The most common PET/CT examinations in Russia are whole-body (WB) and brain examination with ^{18}F-FDG. The proposed DRL, for internal exposure, for such WB examination is 350 MBq and 190 MBq for the brain examinations. The proposed DRL, for external exposure, for the WB examination is 1000 mGy cm and 340 mGy cm for the brain examination. The proposed DRLs for the combined PET/CT examinations are 22 mSv for WB and 5 mSv for brain.

S12-P4

Staff eye lens dose in interventional radiology and cardiology

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Introduction

The eyes of the staff members in interventional radiology (IR) and –cardiology (IC) are exposed to ionizing radiation during medical procedures. In the ICRP statement on tissue reactions [1], the threshold for radiation-induced cataract formation is now considered to be 0,5 Gy absorbed dose. Since then, IAEA and EU have lowered the limits for eye lens equivalent dose in their respective safety standards to be 20 mSv per year averaged over five consecutive years, and 50 mSv in any single year [2-3].

The implementation of the reduced dose limits in the Finnish legislation [4] necessitates reviewing national eye dosimetry practices and developing better methods for the estimation of eye lens dose of exposed staff members in medicine. Personal eye dosimetry by dedicated eye dosimeters measuring the personal dose equivalent $H_p(3)$ is not commonly implemented in Finland. Estimating the eye lens equivalent dose from the depth and/or surface dose readings of the personal dosimeters currently in use presents an interesting alternative for its superior simplicity and cost-effectiveness compared to dedicated eye dosimeters.

Purpose

We aim to develop models for estimating occupational eye lens dose for IR and IC staff. Our project, started in January 2019, is collaboration between the Radiation and Nuclear Safety Authority of Finland (STUK), HUS Medical Imaging Center and University of Helsinki.

Methods

Literature review and a survey of exposure parameters

Since the update in eye lens threshold dose by ICRP and the subsequent changes in recommended dose limits, the estimation of eye lens dose has been, and continues to be, a subject of high research interest. Thus, we have conducted a literature review to identify the relevant results from previously published studies on eye lens dose.

The development of a model for eye lens dose estimation requires up-to-date knowledge on the types of procedures performed, exposure parameters, protective equipment and types of personal dosimeters used in the IR and IC clinics. To gather this information, we surveyed 12 Finnish hospitals about the exposure parameters in different procedures, the staff dosimetry and radiation protection practices used in their IR and IC departments.

Building the model: measurements and simulations

In order to verify the existing data and to deepen our understanding on the exposure conditions, laboratory measurements on the effect of different parameters on eye lens dose are necessary. The possibility of using other quantities, such as depth ($H_p(10)$) and/or surface ($H_p(0.07)$) dose

measured from current personal dosimeters, to estimate eye lens dose will be investigated. The ratios between the dose quantities in various clinically relevant setups will be assessed.

Validating the model in clinical practice

A measurement campaign will be conducted for the purpose of validating the developed model. Personal eye dosimeters will be distributed to volunteering clinics, and the readings from the eye dosimeters will be compared to the predictions of our model.

Results and discussion

A brief overview of the first results will be presented in our poster at the conference.

Conclusions

In our poster presentation, we summarize the goals, methods and current status of our project. A brief summary of the exposure parameter and radiation protection practice data collected from the clinics and preliminary results from laboratory measurements of dosimeter responses performed in STUK dosimetry laboratory are also presented.

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S12-P5

Inspection remarks on transportation of nuclear medicine sources

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In transport of nuclear medicine sources, ensuring an appropriate level of safety is a co-operative process between sender, carrier and receiver. All counterparts have different roles, responsibilities and competences. In Finland these are regulated and inspected by various authorities. Radiation and Nuclear Safety Authority (STUK) licenses and inspects medical use of radiation. Finnish Transport and Communications Agency (Traficom), police and STUK share responsibility for overseeing the transport of radioactive material. In this study we report results from stop checks and inspections on transports of radioactive material to nuclear medical facilities made by police and STUK. A checklist for inspection is introduced together with practical recommendations for improving radiation safety in carrier-receiver interaction.

S12-P6

Radon communication in Finland

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Introduction and Purpose

Radiation and Nuclear Safety Authority in Finland (STUK) has employed various means to increase radon awareness over the years. These include, for example, giving lectures at various events, publishing media briefings and other written material on several radon related topics and participating in many fairs with building construction or indoor air quality as topics. STUK has also organized training in radon mitigation methods for private house owners and construction companies.

Radon communication at workplaces has so far been quite small-scale. STUK has, for example, distributed paper leaflets and maintained internet pages concentrating on workplace related radon matters.

Main points in radon communications, on which STUK wants to increase awareness are

- Indoor radon exposure increases the risk for lung cancer
- Indoor radon levels should be measured in all Finnish dwellings in detached, semi-detached and row houses as well as in the ground floor apartments of multi-strorey buildings.
- Measuring indoor radon is cheap and easy
- In case indoor radon level is high, radon mitigation should be applied
- Applying radon mitigation methods is easy and affordable.
- In Finland the employer is responsible for measuring indoor radiation levels in certain areas and in certain types of workplace buildings.

Radon levels in dwellings have been measured already since 1980s. At first, during 1980s and 1990s, radon measurements were mainly organized by municipal health officers with strong collaboration with STUK. From the beginning of 2000s, STUK organized regional radon campaigns together with municipal health authorities. Training in radon mitigation methods for construction companies was started in these companies. The radon campaigns were very effective first and approximately 40 000 private dwellings were measured during the campaigns by the year 2014. However, the efficacy of these campaigns decreased gradually, which gave way to alternative ways of spreading information to the public. These novel ways have been developed, for example, together with professional communications consults.

According to STUK's experience, part of the employers do not recognize their responsibility for measuring indoor radon levels at workplaces. Regulatory supervision at workplaces is the primary method for enhancing radon measurements. Due to limited resources, it is not possible to have all Finnish workplaces supervised. Therefore effective communication is a cost-effective means to enhance radon knowledge at workplaces. It is estimated that indoor radon levels have been measured only in ten percent of workplaces. Thus, a lot remains to be done to increase the knowledge of radon among employers.

Methods

For public

One new approach is to target communication at specific groups. Examples of STUK's new radon communication strategy are:

- "Bucket Jamboree". STUK distributed 100 plastic buckets accompanied by a free radon measurement at a shopping mall in the city of Hämeenlinna. The plastic buckets were very wanted, but only about 60% of these free radon measurement boxes were returned to STUK radon laboratory for analyses after the measurement period. As a part of this Jamboree, STUK contacted directly some journalists by sending two empty glass bottles with a question: "Which one contains radon?" And the correct answer, of course, was: "It cannot be known. The only way to find out the indoor radon level is to make the radon measurement". The Jamboree ensued several interviews to STUK's radon experts and, for example, one short TV appearance in a fairly popular talk show.
- STUK contacted 12 maternity clinics in Kymenlaakso county, a high radon risk area, and submitted information packages for families visiting the clinic. The package contained a radon-themed puzzle for the child and information leaflets for the parents.
- A puzzle-leaflet "Oppi&ilo" [Figure 1]. The leaflet contained simple tasks and puzzles for small children as well as information on radon and ultraviolet radiation for parents. The leaflet has been distributed widely in Finland, for example, via libraries and maternity clinics and as a attachment to "Meidän perhe" –magazine which is a magazine for families with children. Currently, the distribution has been approximately 65 000 leaflets.
- Intensive social media communication from October 2017 to January 2018. This included, for example, very active role of STUK in Twitter and Facebook.
- Co-operation with fairly well-known Finnish bloggers. Readers could follow how radon measurements were carried out in the blogger's home. Blog readers could ask radon-related question in the blog's chat and STUK's radon expert answered these questions. The discussion on the blog site was very active.
- "Radiation radio". A radio series on several topics on the area of radiation where one episode was indoor radon. The episodes can be listened as podcasts on Radio Suomi's website after the actual broadcasting time.

At workplaces

In November 2018, STUK sent a survey to all occupational safety representatives in Finland to gain information on their awareness on statutory radon issues. This was first time STUK contacted occupational safety representatives. The collected answers have not yet been analyzed. The results of this survey will be utilized when STUK prepares new information material for the workplaces and applies novel communication methods with employers. The purpose is to collect information on the facts which could help employers to fulfill their responsibility with radon measurements at workplaces.

Discussion

These new methods surely have, at least, inspired some groups to perform radon measurements at home. It seems that nation-wide news on radon topics have been the most effective way to encourage public to order radon measurements for their homes. When nation-wide media (tv-show, newspaper, etc.) publish news on radon in indoor air with encompassing content, there is a clear increase in radon measurements orders and visits to STUK indoor radon webpages[Figure 2]. For example, when Helsingin Sanomat (the newspaper with the highest national circulation) published an article (February 2017) on radon, there was a temporal increase of 1300% in radon measurement orders from STUK's radon laboratory. However, one has to bear in mind, that radon measurement orders from STUK's radon laboratory as well as visits to STUK's webpages are not an extensive representation of increase of radon awareness. In addition, more radon measurement are also ordered from other radon laboratories, the amount of which STUK does not know.

Still, the media is eager to publish fresh and emerging news on different topics. Indoor radon has been studied for such a long time it is not very likely that revolutionary findings are yet to be found in that area. Therefore developing new and interesting indoor radon related communication which would encourage the media to publish nation-wide news on radon also in the future will be a challenge.

Radon communication in the social media (Facebook, Twitter) or at fairs could attract radon awareness attention. However, they do not increase radon measurement orders or visits to STUK's radon webpages. Or at least the effect of the social media is not concurrent. It should be pondered at STUK how radon communication in the social media and at fairs could be developed further.

Currently, indoor radon levels have been measured on average in one tenth of the private dwellings in the whole Finland. In high radon risk municipalities, up to 50% of dwellings has been measured. According to our studies, in approximately half of the dwellings, where radon levels are high, radon mitigation has been applied. There is a clear need to continue the new communication means, i.e., the targeted communication as well as nation- wide media campaigns.

Conclusion

STUK's radon communication has been renewed in the recent years. The direction of this communication reform has been right and there is no going back to old regional radon campaigns. Especially those kinds of radon communications which yield nationwide media visibility, seems to be desirable .

Fig. 1. Puzzle leaflet for children on radon and ultraviolet radiation

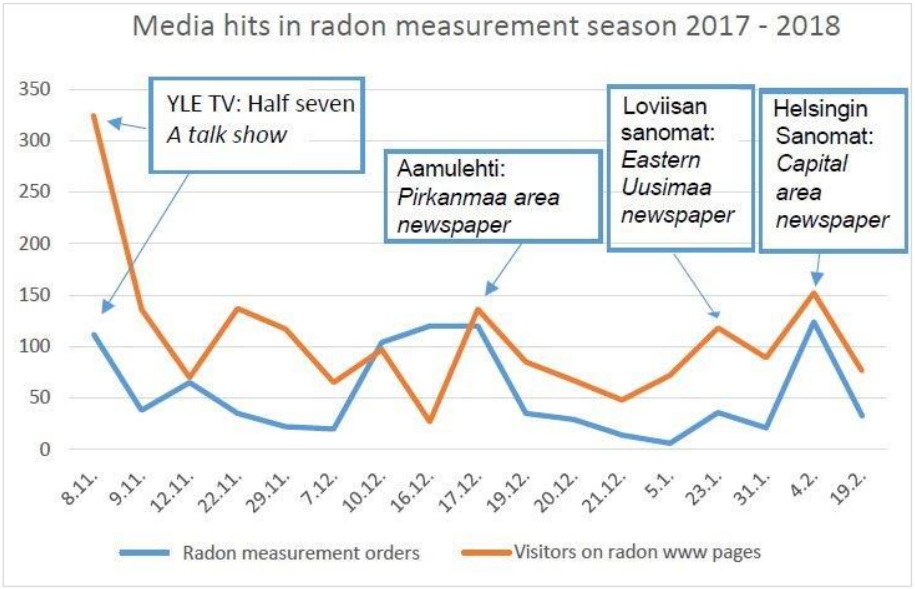

Fig. 2. Media hits on indoor radon and their relation to radon measurement orders from STUK radon laboratory and visitors on STUK radon ww

S12-P7

FINNORM – Establishing the NORM inventory of Finland

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On January 2019, Radiation and Nuclear Safety Authority (STUK) launched a new project called FINNORM, that aims to recognise the industrial activities where naturally occurring radioactive materials (NORM) may be present. The importance of surveying these activities has been recognised in Finland for some time and it became mandatory when the reformed Radiation Act came into force in December 2018. The project will be carried out by the authority as it requires knowledge of the Radiation Act, experience of regulatory control and co-operation with the industrial sectors.

FINNORM –project aims to identify all the industrial sectors in Finland where NORM may occur or be of concern. To reach this aim, a comprehensive national NORM survey will be conducted. The survey will include on-site measurements, as well as sampling, performed in industrial places where NORM may occur, such as old legacy sites. The survey will be collected into a inventory that will give up to date information about existing NORM for the supervising authority.

One of the requirements that the new Radiation Act brings is that Finland's authorities need to establish a national program for the management of radioactive waste. The information collected in the project will be provided for the preparation of the national waste management plan.

The scope of the poster is to show the present state and progress of the project and share the most important points of the experience we have learned so far in building a national NORM inventory.

S12-P8

Radiation safety in aviation in Finland

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Introduction

Since 1970s, emphasis on ALARA has made remarkable improvements in reducing annual exposure for radiation workers in most fields of activity. However, aircrew is a notable exception to this progress. Aircrew exposures remain at levels substantially above those of other radiation-exposed workers and are increasing with modern flight operations. Members of aircrew are exposed to radiation and their doses are higher than in any other field of activity also in Finland. Fortunately, sudden high doses aren't usually possible.

Aircrew members are exposed to galactic cosmic radiation on every flight and occasionally to solar protons on polar flights. The cosmic radiation field in aircraft is affected by altitude, geomagnetic latitude, and solar cycle. At normal aircraft altitudes and at the equator, electrons/positrons and neutrons are the main components in dose, followed by protons. In contrast, at higher latitudes, the dose is mainly from neutrons. Additionally, at higher altitudes, nuclei heavier than protons (e.g. alpha particles) start to contribute. The additional exposure due to solar flares remains unpredictable. No personal dosemeters are available for measuring cosmic radiation for aircrew because large range of energies and particle types should be measured.

According to the Radiation Act (859/2018), which came into force on 15 December 2018, airlines need a safety license in Finland if the dose of workers can exceed 1 mSv per year (flight altitudes > 8 km). At the same time, members of aircrew became radiation workers. Pursuant to the Radiation Act (859/2018) STUK has to maintain dose register for workers exposed to radiation. The Finnish dose register has been established in 1963 and it includes exposure data for all workers engaged in work involving the use of radiation, the use of nuclear energy and the exposure from natural radiation. Radiation exposure of the workers in aviation has been monitored since the early 1990s and from 2001 the regulatory control has been done on regular basis. The airlines deliver the calculated effective doses of aircrew annually to the dose register.

Results and discussion

In 2018, aircrew (1,306 pilots and 3,042 members of cabin crew) represented 27% of the 16,350 workers monitored for radiation exposure in Finland, but their collective effective dose of 13.5 manSv constituted vast majority (83%) of the total collective effective dose of 16.3 manSv for all workers [1]. The 4,794 workers in the use of nuclear energy had a collective effective dose of 2.4 manSv representing 15% of the total collective dose among the Finnish workers in 2018. Therefore, the collective effective dose to the members of aircrew was about fourfold compared with that of the users of nuclear energy even though the number of workers was of the same magnitude in both fields of activity. Workers in the fields of industry and health care (other than X-

radiation) received both 1% of the total collective effective dose. In all other fields of activity [i.e. health care (X-radiation, up to 150 kV), research and education, veterinary medicine, manufacturing of radioactive substances, installation/services/technical trial use, trade/import/export and services], the collective effective dose was less than 1% of the total collective effective dose in 2018.

In Finland, the number of aircrew has increased stepwise during this millennium (Fig.1.). The number of pilots and cabin crew remained fairly stable between 2001 and 2005. In 2006, there was a sudden increase in the number of pilots and cabin crew; addition of 58% and 38%, respectively. After that the number of air personnel remained quite stable until 2017 and 2018 when especially the number of cabin crew grew rapidly. Between 2001 and 2018, the total increase in the number of pilots has been 93% and that of cabin crew 74%.

The annual collective effective dose (Fig.2) to aircrew has increased over the years. In this millennium, the annual collective effective dose to aircrew has increased over threefold; from 1.1 manSv to 3.7 manSv for pilots and from 3.0 manSv to 9.9 manSv for cabin crew. The increase of the annual collective effective doses has been most remarkable during the last three years. The collective effective dose to cabin crew has shown rapid increase; 62% from 2015 to 2018. The annual collective effective dose to pilots has increased far less; 38% from 2015 to 2018.

In this millennium, the mean annual effective dose to pilots and cabin crew has increased 1.7- and 1.9-fold, respectively (Fig. 3). The mean annual effective dose increased rapidly from 2015 to 2016; 19% for cabin crew and 14% for pilots.

The distribution of the effective doses to pilots and cabin crew in 2018 can be seen in Figure 4. For pilots, the shape of the dose distribution resembles normal distribution with a maximum at 3.3 mSv. For cabin crew, the shape of the dose distribution is weighted to the bigger doses with a maximum at 4.7 mSv. In fields of activity other than aviation, the dose distribution is typically close to the exponential distribution.

Airlines prefer nowadays to use the most direct transpolar [2] routes where the flight time is shorter but the radiation exposure is higher. Over last few years, airlines have been flying more and more polar routes because they are shorter and have reduced headwinds. This saves time and fuel. However, on a typical day when the sun is quiet, dose rates for flights over poles are three to five times higher than for flights closer to the equator.

The magnitude of radiation exposure depends on flight time, altitude, route (latitude and longitude) and on periodic fluctuations in solar activity. The generalisation is that cosmic radiation exposure is greater on longer flights, at higher altitudes and those nearer the poles. Risks to the flight crew is minimised by carrying out a flight planning where flying various other routes, at least part of the time is also considered.

The growing annual collective effective doses and the increase of the mean annual effective dose can mainly be explained by the changes in the Finnish aviation. In recent years, new routes have been opened from Finland to the Far East and the number of long-haul flights has increased in general. The fleet used by airlines has been replaced with new ones and new aircraft are flying higher than before. Also the northern location of Finland contributes to the higher exposure to the

Finnish aircrew when compared to most countries in the European Union, as the magnetic field of earth gives less protection near the polar area than the equator. In addition, the growing effective doses are partly explained also by the vicinity of the solar activity minimum which is reached in 2020.

The increase in the mean annual effective doses has remained moderate due to the practice of the Finnish airlines to use a reference level of 6 mSv per year as a maximum radiation exposure allowed to their workers. This is in harmony with the ICRP Commissions recommendation that a reference level in the 5-10 mSv per year range should generally be selected [3]. To remain below the reference level, the airlines have had to reduce the exposure of some of their workers by limiting working hours and taking into account the flying routes in shift arrangements.

Conclusions

Doses received by aircrew due to their exposure to cosmic radiation are higher than in any other field of activity. The doses have increased significantly during the last years. It is important that realistic dose assessments are made in order to ensure appropriate protection for members of aircrew who can´t avoid the occupational radiation exposure.

Important aspect of the radiation protection of aircrew is to provide information of cosmic radiation and its effect to health. Especially important is appropriate protection for female crew during pregnancy and thus keeping the fetal dose as low as possible and at least under 1 mSv after the pregnancy has been announced.

During the last years, the number of flights has increased very rapidly. Future challenges include development of new ultra-long range aircraft that can fly at high altitudes longer routes (over 15 hours) which may also lead to considerable dose increments. Future challenges may be managed by seeking for synergy effects between radiation protection, flight safety and airline business needs. In Finland, the airlines have restricted the exposure of their aircrew to less than 6 mSv per year. They are willing to continue this also in the future which is crucial for the radiation protection of the aircrew.

References

1. The Finnish national dose register
2. http://hpschapters.org/njhps/ShonkaAircrewRadExposure.pdf
3. ICRP, 2016. Radiological protection from cosmic radiation in aviation. ICRP Publication 132. Ann. ICRP 45(1), 1-48.

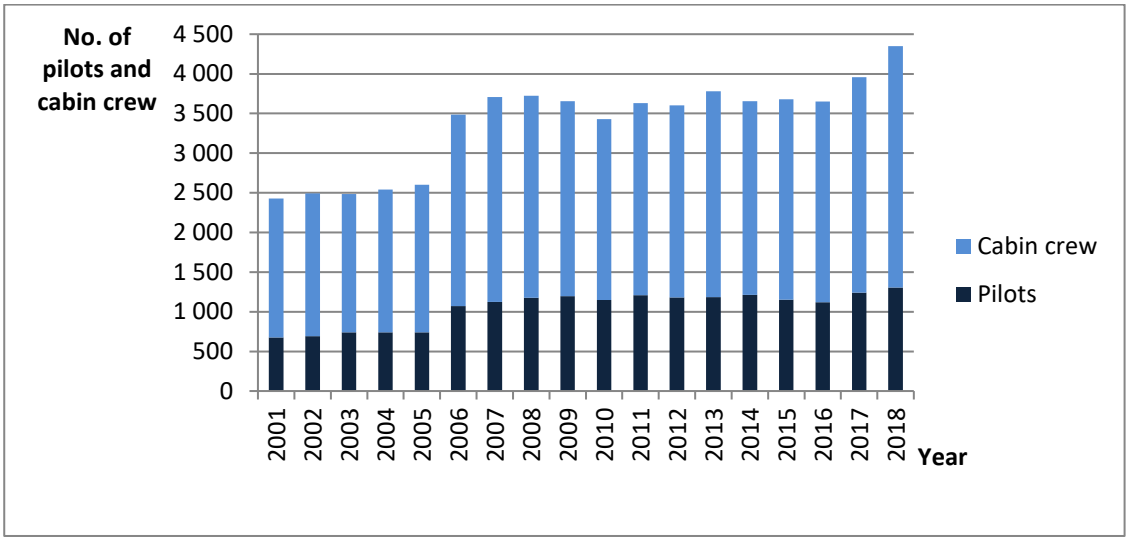

Fig. 1. Number of pilots and cabin crew in Finland in 2001-2018.

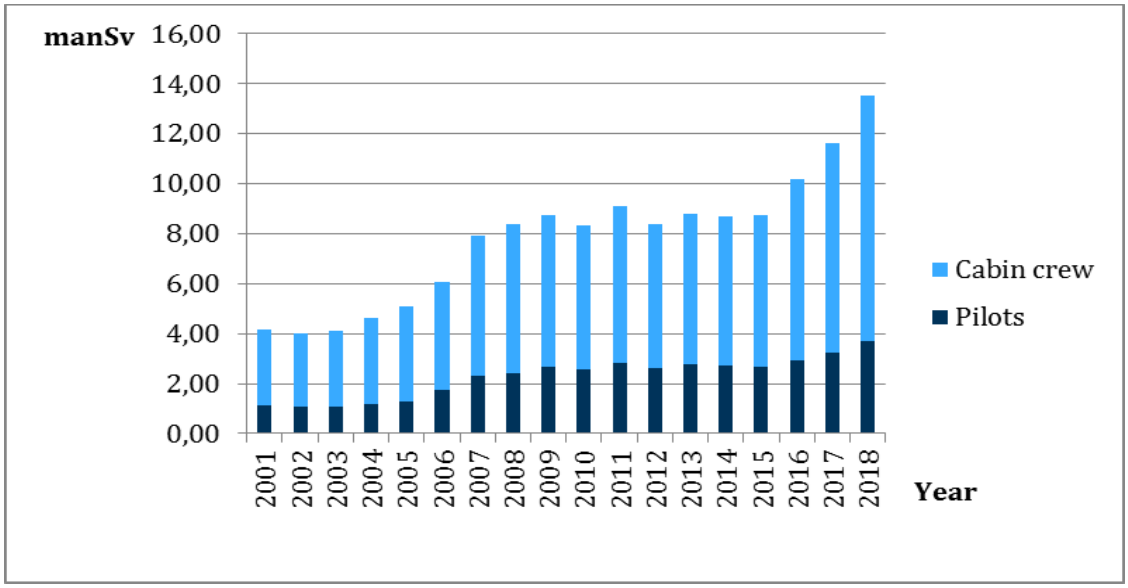

Fig. 2. Annual collective doses to aircrew in Finland in 2001-2018.

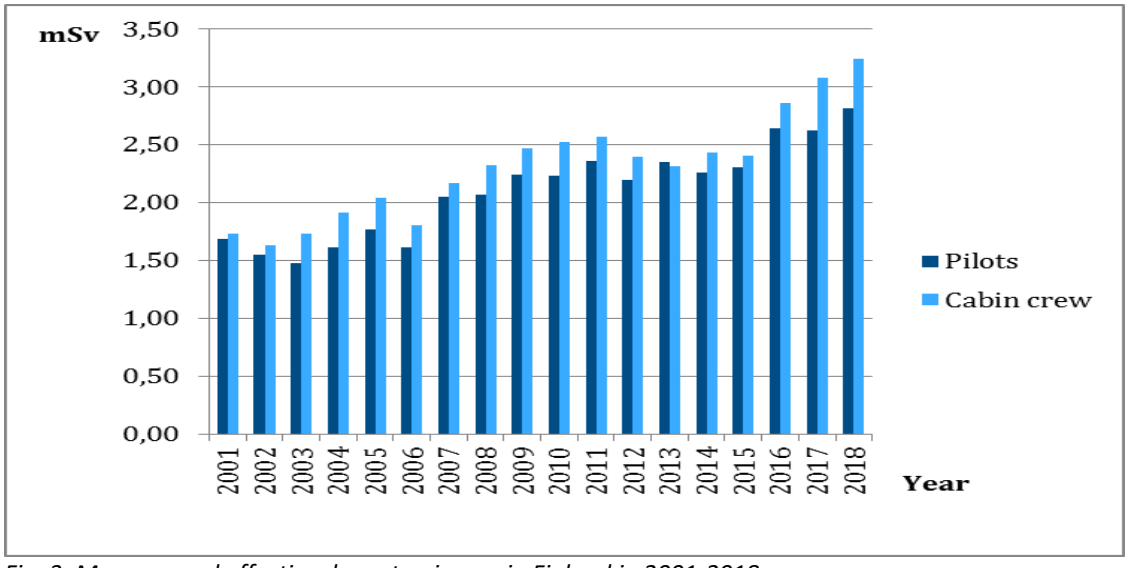

Fig. 3. Mean annual effective doses to aircrew in Finland in 2001-2018.

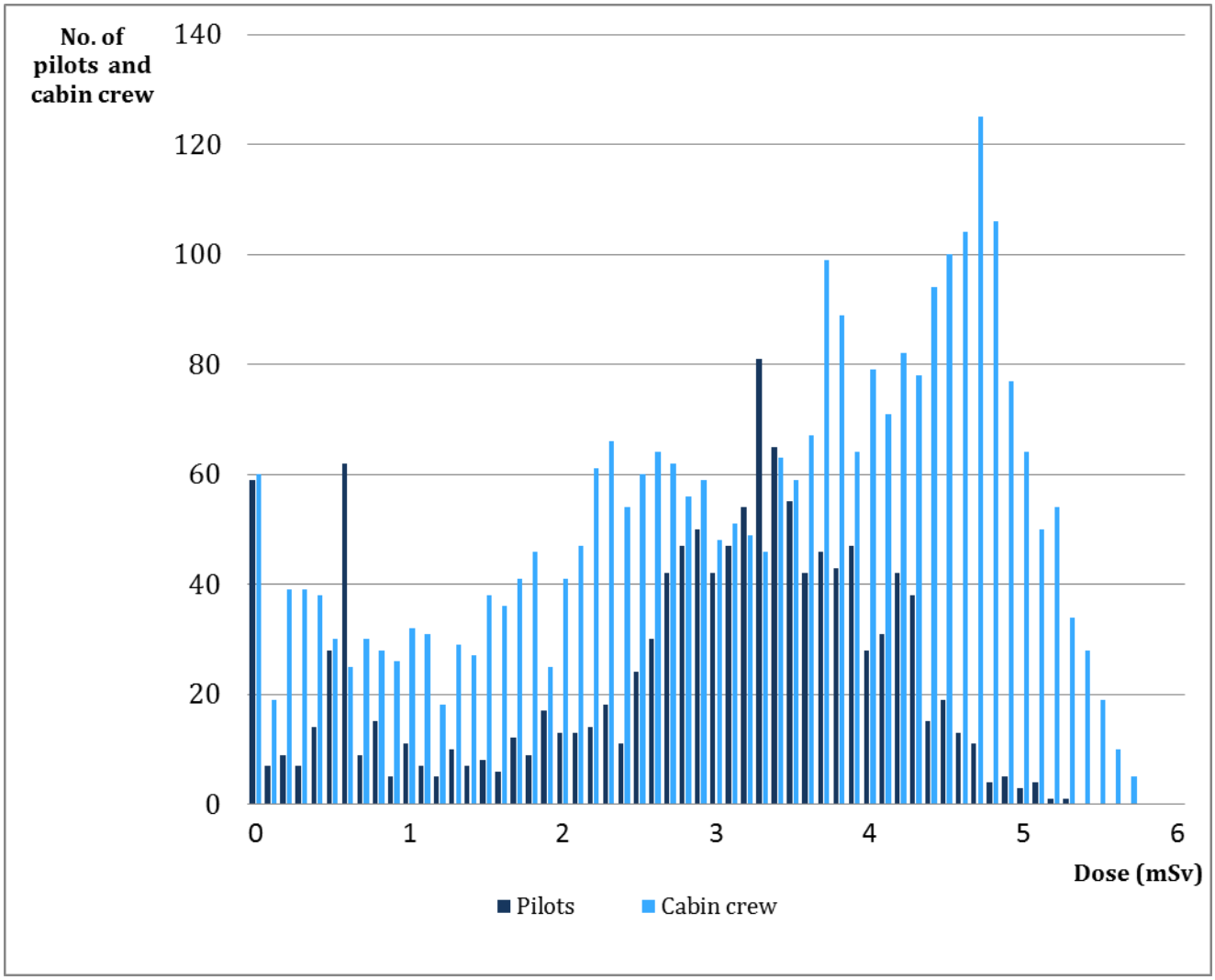

Fig. 4. Distribution of effective doses to aircrew in Finland in 2018.

S12-P9

General Overview On Nuclear and Radiological Regulatory Commission (NRRC) In Saudi Arabia

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Saudi Arabia is increasing its efforts in meeting the growing demands in energy by incorporating alternative sources of energy in its energy mix to reduce the dependence on fossil fuel. Nuclear energy is one of the alternative energy which can assist in the electricity power generation and water desalination. King Abdullah City for Atomic and Renewable energy (K A CARE) was initiated by a Royal order on April 17, 2010 with a mandate to contribute to sustainable development in Saudi Arabia related to renewable and atomic energy for peaceful purposes, to upgrade the standard of living and improve quality of life in Saudi Arabia and to create additional employment and investment opportunities. In July 24th 2017, Saudi Government approved the SNAEP to implement a civil nuclear program. K A CARE has established a strategic partnership with Radiation and Nuclear Safety Authority, STUK on support for development of nuclear regulatory practices and nuclear regulations for the Kingdom of Saudi Arabia. In the first phase during 2017 the development of the regulations has focused on licensing, Safety, Security, Safeguards, management system and siting. The collaboration has covered also support to K A CARE in its effort in drafting the legislation framework for Saudi Arabia in 2017. In 2018 Saudi Arabia has reached the readiness for the establishment of an independent national nuclear regulator as a spin-off from K A CARE. Government decision dated 13th March 2018 approving the establishment of Nuclear and Radiological Regulatory Commission (NRRC) was issued. The NRRC consists of three sectors including Radiological Regulatory Sector, Nuclear Regulatory Sector and Environmental, Early Warning System and Emergency Regulatory Sector.