OPTIMIZATION OF RADIATION PROTECTION

ALARA: A Practical Guidebook

The European ALARA Network Edition

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FOREWORD

In 2009, the European ALARA Network created a Working Group on ALARA Culture. The objective of the working group is to maintain and further develop a high level of radiation protection by promoting ALARA culture in all fields of application, implementing the ALARA principle into practice, and analysing feedback from implementing ALARA in various sectors.

As part of ALARA culture dissemination, the Working Group has written this practical guidebook on optimization of radiation protection (herein called "the Guidebook"), to be used by radiation protection professionals or other stakeholders involved in the ALARA processes.

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INTRODUCTION

The ALARA Principle

The system for radiological protection recommended by the International Commission on Radiological Protection (ICRP) is based on three principles: Justification of radiation exposures, optimization of radiation protection (or ALARA[1]) and application of individual dose limits.

According to ICRP Publication 103 (ICRP, 2007), optimization of protection is the process by which "the likelihood of incurring exposures, the number of people exposed, as well as the magnitude of their individual doses should be kept As Low As Reasonably Achievable taking into account economic and societal factors".

The principle is included in Article 5 of the European EURATOM Basic Safety Standards (EC, 2013) with the following wording: "Radiation protection of individuals subject to public or occupational exposure shall be optimised with the aim of keeping the magnitude of individual doses, the likelihood of exposure and the number of individuals exposed as low as reasonably achievable taking into account the current state of technical knowledge and economic and societal factors. The optimization of the protection of individuals subject to medical exposure shall apply to the magnitude of individual doses and be consistent with the medical purpose of the exposure, as described in Article 56. This principle shall be applied not only in terms of effective dose but also, where appropriate, in terms of equivalent doses, as a precautionary measure to allow for uncertainties as to health detriment below the threshold for tissue reactions."

The principle of optimization of radiation protection is a direct consequence of the adoption of the linear dose-effect relationship with no threshold for "stochastic effects". It resulted in a search for risk reduction whatever the level of exposure, while taking into account economic and societal factors. The wording of the ALARA principle has evolved through various ICRP publications, developing the question of how far the risk should be reduced (see Appendix A).

According to ICRP Publication 101 (ICRP, 2006), ALARA is a frame of mind, always questioning whether the best has been done in the prevailing circumstances. It requires a forward-looking iterative process aimed at preventing exposures before they occur. It is continuous, taking into account feedback experience as well as technical and socio-economic developments. It requires both qualitative and quantitative judgments. Thus ALARA is an obligation of means, and not an obligation of results, in the sense that the result of ALARA depends on processes, procedures, and judgements and is not a given value of exposure.

[1] "ALARA" (As Low As Reasonably Achievable) has been used for more than 20 years by radiation protection professionals. It is considered that the two expressions – optimization of radiation protection and ALARA - are synonymous and interchangeable (ICRP, 2006).

Why a practical guidebook on ALARA?

In the late 1980's, the ALARA principle benefited from many theoretical developments aimed at detailing the "ALARA procedure" to help structure the implementation of ALARA. A European report "ALARA - From Theory towards practice" was published in 1991 (EC, 1991) providing a reference manual on both theoretical and practical aspects of ALARA.

Since then, ALARA has been implemented in various exposure situations and it is clear that, while the basic steps of the ALARA process remain the same whatever the exposure situation, the practical implementation of this process may vary from one situation to another.

The objective of this Guidebook is to provide a comprehensive overview of the ALARA process, and to describe the main actors and their responsibilities. The aim is also to illustrate the implementation of the ALARA process with practical examples of the optimization of protection of workers and the public in various exposure situations, for example patient protection in medical exposure situations as well as for emergency and post-accident situations. Most of these examples come from the experiences of EAN Members as well as from EAN Workshop presentations over more than 20 years. To help understand the role of ALARA in the radiation protection system, the basic concepts of radiation protection, their origins and the role of the various organizations contributing to its elaboration are also described in the Appendices.

Examples in the Guidebook

Chapter 7 presents practical and concrete examples of the application of the ALARA principle in various situations. As far as possible, the examples are presented using the same format:

- Presentation of the context and/or issues at stake;
- Methodology;
- Main results;
- Lessons-learned;
- References.

The examples come mainly from communications made during EAN Workshops or other radiation protection congress. The Working Group consulted with the contributors for additional details when necessary. Readers are invited to consult the references for further information.

This Guidebook is dedicated to all stakeholders involved in radiation protection who wish to improve their understanding of ALARA from theoretical but also practical points of view: competent authorities, licensees, manufacturers, suppliers and designers[2], radiation protection professionals, professional associations, exposed workers or members of the public.

[2] "Manufacturers, suppliers and designers" are to be considered in the broadest sense. For example, they can be involved in the manufacture, supply or design of ionising radiation systems (in the medical field for example), facilities where ionising radiation will be used, tools to be used in a radiation environment, personal protective equipment, etc..

References

EC, 1991. Radiation Protection, ALARA - From Theory towards practice, Commission of the European Communities Report EUR 13796, EN.

EC, 2013. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom.

ICRP, 2006. The Optimization of Radiological Protection - Broadening the Process, Annexe 1 Assessing dose of the representative person for the purpose of radiation protection of the public, ICRP Publication 101b. Ann. ICRP 36 (3).

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4).

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1 OPTIMIZATION IN PRACTICE

1.1 The ALARA process

The ALARA process is essentially a methodology for identifying, evaluating and selecting radiation protection actions in order to reduce the magnitude of individual doses, the number of people exposed and the likelihood of potential exposure of the workers, public and patients to a level that is as low as reasonably achievable (ALARA). In this process it is necessary to evaluate the scope of the problem, the magnitude of the resources to be committed and the level of protection that can be achieved, and any other factors influencing the decision, to achieve the best radiation protection solution, taking economic and societal factors into account.

Searching for a balance between investments in radiation protection actions and the radiation protection benefits they produce can be a complex exercise. Resources are not infinite and we need to take into account protection from other risks as well as socio-economic factors. In some cases, it can lead to situations where the scientific or engineering analysis must be coupled with value judgements of the different stakeholders involved in the process. In these cases, decision-making tools can be of value in order to assess the importance of such value judgements. However, before we apply these techniques it is necessary to establish a list of radiation protection methods, taking into account the scope of the ALARA problem at hand.

The ALARA process is very similar to any risk evaluation and risk management analysis. A schematic view of the various steps of the general ALARA process is given in Figure 1. The specific implementation of this process with respect to different exposure situations will be discussed in the next chapters.

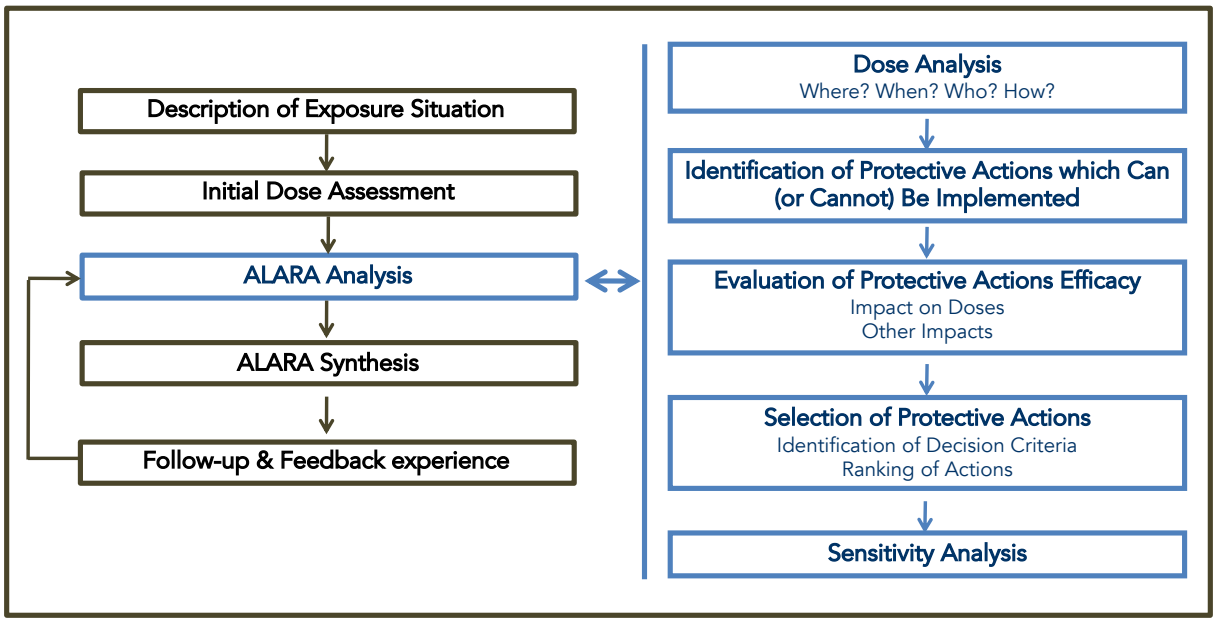

Figure 1. – Schematic of the ALARA process.

1.1.1 Description of the exposure situation

In this step, information is gathered to describe in a broad way the exposure situation and to evaluate globally the issues in terms of radiation protection. This description will typically respond to the following questions:

- Is it a planned exposure, an existing exposure or is it an exposure in an emergency situation?
- What are the sources of exposure?
- What are the pathways of the exposure (external, internal)?
- What is the number of people that will be exposed and how are they categorised (workers, patients or public)?
- What is the frequency of exposure?
- Any other pertinent information?

1.1.2 Initial dose assessment

The initial dose assessment, taking into account existing radiation protection measures will help establish the importance of the ALARA issue (level of individual and collective dose) and provide an initial level of exposure for the ALARA analysis to be performed.

A first judgement should be made from the initial dose assessment to determine the effort that should be put into considering further dose reductions. The effort devoted to the ALARA study should be commensurate with the initial level of exposure and the estimated dose savings.

Assessing the level of exposure to ionising radiation of an occupationally exposed person, a member of the public or a patient is not straightforward. Assessments are usually made based on dose and dose-rate measurements in situ and combined with calculation tools to achieve a better understanding of the exposure situation and enable further optimization.

The methods or calculation tools used are selected based on the knowledge of the possible exposure geometries, exposure pathways and on the characteristics of the ionising radiation involved in the assessment. The calculation methodology depends on the type of radiation, the radionuclides and the desired precision; the results will depend on the level of competence in using the tools.

Two main groups of calculation tools can be identified, one evaluating direct external exposure to radiation, the other more related to exposure from radioactive material that is dispersed in the (work or natural) environment and leads to internal and external exposure.

1.1.2.1 Calculation tools for assessing external exposure

For external exposure the main steps in calculating the exposure level involve:

- The determination of the source(s) of the ionising radiation;
- Evaluation of the possible time evolution of the sources (radioactive decay, possible activation, etc.);
- Calculating the attenuation and propagation of the ionising radiation;
- Determining the dose to a person.

Different calculation tools are available, from highly detailed Monte Carlo simulations of the propagation of ionising radiation to more simplistic calculation techniques such as linear attenuation with build-up correction. Each has its advantages and disadvantages with regard to speed of calculation, accuracy and user friendliness. The limits of the tools must be fully understood by the user in order to draw the correct conclusion from the results and their uncertainties[3].

For external exposure assessments in workplaces, the development of dose evaluation tools has been coupled recently with 3D rendering or simulation. This combines the strength of dose calculation tools with an effective visualisation of the workplace enabling a better understanding of the exposures from ionising radiation in the workplace.

1.1.2.2 Calculation tools for assessing internal exposure

The assessment of exposure level to radioactive material dispersed in the (work) environment is usually made according to the following steps:

- Determination of the source term;
- List of radionuclides that are (will be) dispersed in the environment;
- Modelling the dispersion of the radioactive material;
- Calculating the external and internal dose from the exposure of the person.

Different radiation protection tools are available to evaluate the dose due to the release of radioactive liquids, gases and aerosols. These were developed mainly for and by the nuclear industry to assess doses received by the public in routine or accident situations. They take into account meteorological data and the different pathways leading to the exposure of the individual or the most exposed member of the public.

The long-range dispersion models are well established in the field. Further development is ongoing for the short-range and in-building dispersion of material.

1.1.3 Dose analysis

The initial dose assessment should then be used as the first step of the further ALARA analysis aimed at identifying the main contributors to the individual and collective dose. This step can be structured by answering the following questions:

- **When** does the exposure take place? (i.e. identify any key moments or steps regarding exposure etc.);
- **Where** does the exposure take place? (i.e. identify the high dose area etc.);
- **Who** is exposed? (i.e. identify the most exposed individuals etc.);
- **How** are the individuals exposed? (i.e. identify the characteristics and parameters that have an influence on the radiological exposure conditions, the duration of exposure etc.).

[3] It is clear that numerous radiation protection software has been developed over decades to assess the external exposure of individuals. It is not the intention of the authors to make a comprehensive list in this publication.

1.1.4 Identification of protective actions which can (or cannot) be implemented

The identification of the protective actions together with their characteristics and constraints is probably the longest part of the optimization process.

Dose reducing measures are best identified by examining the principal means for exposure control (appropriate for the type of exposure situation) such as:

- Reduction of the source activity (dose rate);
- Increasing the distance to the source;
- Use of shielding;
- Use of personal protective equipment;
- Reduction of the exposure time;
- Reduction of the number of persons exposed;
- …

This identification process should not only be undertaken by radiation protection specialists but should involve other stakeholders to be identified according to the exposure situation (for example: exposed individuals, those having an input to the exposure situation such as designers and engineers, …)

Feedback from other similar situations, difficulties encountered, new materials and methods used etc. can also be useful input at this stage. A checklist of possible protective actions, adapted to the type of exposure situation or to the field of activity, can also be useful at this stage (see Appendix C).

1.1.5 Evaluation of the efficacy of protective actions

An accurate evaluation of the effectiveness of each protective action in terms of dose reduction (collective and/or individual) is an essential step, together with an evaluation of the other impacts associated with their implementation (cost, feasibility, quality, safety, waste, releases, …) to decide whether the dose saving that is likely to result from the action is worth the effort needed to achieve that saving.

In assessing the impact of any protective action, one should usually consider:

- The dosimetric impact. This evaluation is almost compulsory. In certain cases, the implementation of a protective action to reduce the exposure of certain individuals may lead to the exposure of other individuals (e.g. installing shielding, decontaminating the environment). This "extra" exposure needs also to be evaluated and integrated in the analysis.
- The cost of the protective action. This should include the total cost of the protective action minus any costs potentially saved by implementing the action (e.g. providing protective equipment, reducing workloads, ...). It has to be expressed in the same unit of time as for the estimated dose saving (e.g. annual cost for an annual dose saving).
- Other impacts. Protective actions may have an impact on a large set of other parameters: human safety, cost, human factors, education and training, environment (if decontamination is used), production of waste, etc. Some of these parameters may be useful indications in the selection process, notably if it is based on a multi-criteria analysis (see 1.1.6.).

Note that the evaluation can be made individually on each action and also on combinations of actions. Multiple variations can be evaluated to identify all reasonable dose reduction outcomes.

1.1.6 Selection of the protective actions

The selection of the protective actions to be implemented can range from a straightforward decision based on expert judgement about their efficiency to a more complex decision-making process including use of tools such as cost-benefit, cost-effective or multi-criteria analysis.

The choice is always a balance between the benefits in terms of radiation protection and all the constraints. The final choice is often the conclusion of an iterative process. If used, the selection criteria should be clearly defined. Generally, the selection of actions (or combination of actions) can be simply based on efficiency and feasibility criteria. However, when other criteria appear to be important in the selection process, these criteria should be listed, described and the impact of the considered action on them evaluated.

Note that the process described here is quite formal and has been historically applied mostly to the protection of workers in the nuclear industry. This whole process may not be fully applied (or even relevant) for other categories of exposure in other exposure situations. This will be considered later.

In some cases, it might be useful to make use of decision-aiding techniques. Such techniques were developed in the late 1980's and early 1990's (ICRP, 1991) to help in the selection of the best protective actions while taking into account all decision-making criteria.

These techniques should be used as a tool to inform and clarify decisions; in addition, they encourage a more thorough examination of the criteria used in the decision-making process, and help ensure that the process is coherent. The choice of technique will depend on the scope of the decision – other factors such as the availability and the quality of the data may also be considered. (A focus on cost-benefit analyses and multi-criteria analysis is provided below).

It has been recognised that these techniques should not be the only tool used for demonstrating optimization, nor are they expected to be used in all cases. They are most useful for complex situations, and/or situations where major financial investments are to be made and/or where intangible parameters play a role in the decision-making.

1.1.6.1 Focus on cost-benefit analysis

Cost-benefit analysis was the first decision-aiding technique introduced by ICRP (ICRP, 1991). The technique relies on the aggregated monetary measures of costs and benefits associated with protective actions, the objective being to identify the protective actions having the minimum total cost.

When radiation protection options are compared using such a technique, the two factors used are the cost of the options and the collective dose associated with these options.

In order to aggregate these two factors, it is necessary to transform the collective dose into a monetary value. For this purpose, the collective dose of each option is multiplied by the monetary value of the

unit of collective dose (the so-called "alpha value" – see Appendix D), in order to obtain the "cost" of the collective dose (also called "cost of detriment").

The analysis then proceeds by adding for each option, the cost associated with its implementation, X, and the derived cost of the detriment corresponding to the resulting collective dose, Y, in order to obtain a total cost (X + Y). The optimum solution is the option with the lowest total cost, as shown in Figure 2.

Thus, this technique considers only economic factors, which means that often extremely important societal factors are not considered. For the latter, multi-criteria analysis can provide an answer.

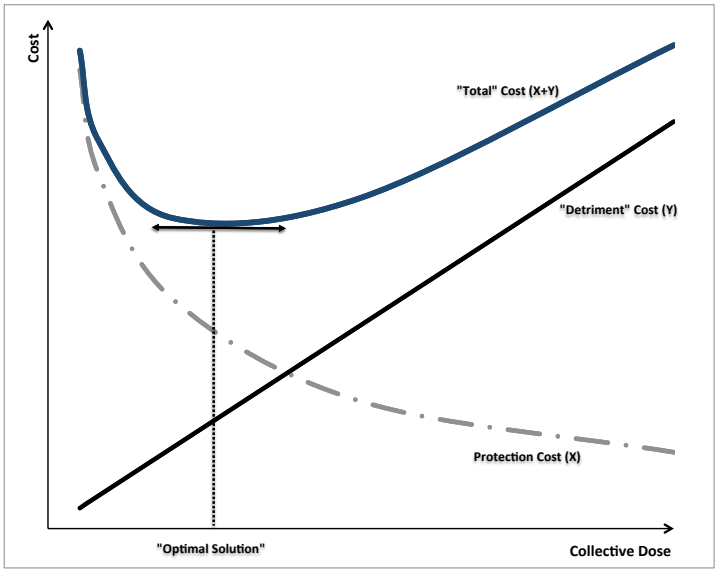

Figure 2. – Cost-benefit analysis.

1.1.6.2 Focus on multi-criteria analysis

Multi-criteria analyses have been developed from various disciplines such as engineering, management sciences etc. and are broadly applicable to many decision processes. The essence of this technique is to use a scoring scheme that can accommodate any type of data. These functions, which do not have to be linear (enabling a modification of importance depending on the magnitude of the impact), are analysed by the decision-makers.[4]

For example, in multi-attribute utility analysis is it is necessary to specify the radiological protection factors and to quantify the consequences of each protection option in terms of these factors; in other words, to carry out the same initial procedure as for a cost–benefit analysis. It is then necessary to generate for each factor a utility function that gives the relative desirability of the possible outcomes for this factor. Generally, the best outcome or the lowest adverse consequence for each factor is assigned a utility of 1 and the worst consequence a utility of 0. A major advantage of this technique is

[4] It can be noted that ICRP 55 (ICRP 55) proposed an annotated bibliography of multi-criteria analysis that can be used. However, according to the date of its publication (1988), it is recommended to search for new developments. In particular, numerous software is now available in this field.

that these utility functions need not necessarily be linear. This enables variations in attitude with the magnitude of consequence to be introduced into the quantitative decision-making process. It is also possible to use the technique of multi-attribute utility analysis to include the factors not normally regarded as quantifiable by assigning utility functions to the various values of the factor.

1.1.7 Sensitivity analysis

The robustness of the final selection should be established by a sensitivity analysis. Uncertainties are inherent in the process as most data may rely on assumptions and models. For example, there are uncertainties in calculations based on atmospheric diffusion models or risk projection models resulting from both an intrinsic lack of realism of the model and the input data. There can also be uncertainties in the evaluation of the time of exposure or the dose rates.

A sensitivity analysis should be undertaken to check if variations in the data used have an impact on the recommended outcome of the ALARA process. In this context it is also good to perform a "What if?" analysis to consider the impact of unexpected conditions arising.

1.1.8 ALARA synthesis

Based on the information prepared in the steps given above we can come to a decision to implement selected protective actions. This decision, as well as the resulting planned optimised exposure situation, needs to be documented for traceability and transparency reasons, and communicated to the stakeholders involved.

It can be noted here that, according to the exposure situation and the radiation protection organisation, the final decision will be taken not only by one person, but by a committee grouping the various stakeholders that might be impacted by the decision.

The ALARA synthesis should contain the description of the selected protection action(s) and the way to implement it (them), as well as the plan for the follow-up of this implementation, the collection of feed-back experience and the review process that will be undertaken to assess the efficiency of the action(s).

1.1.9 Follow up and feedback experience

Specific attention needs to be given to the follow-up of the exposure situation in order to evaluate the efficiency of the ALARA process and detect if any further improvement is needed.

Follow-up includes dose monitoring, performance evaluation as well as collection and assessment of relevant documentation allowing an evaluation of the effectiveness of protection actions. Communication with the different stakeholders is also an essential element to collect feedback.

Performance evaluation and assessment of the effectiveness of the actions undertaken under the ALARA process can be made using various indicators. Two types of indicators may be used:

- Quantitative indicators: based on measurable elements (e.g. evolution of the annual collective and individual doses for nuclear power plants, percentage of patients exceeding a Diagnostic Reference Level in a radiology department etc.). Quantitative evaluations can

also be used for intercomparisons, provided that a consistent approach is agreed between stakeholders.
- Qualitative indicators: related to experience and perception, which are more difficult to evaluate formally (e.g. change in behaviour).

The results of the evaluation process and the collection of feedback experience should be used as an input to continue the ALARA process for further improvement of the exposure situation.

1.2 ALARA culture

The ALARA procedure cannot be implemented effectively when there is no common culture to which the different stakeholders adhere.

The elements that are needed to support an ALARA culture are attitudes towards safety in general and towards dose reduction in particular. Everybody working with radiation must be aware of its risk and must be aware of the requirement to reduce the dose to as low as reasonably achievable.

Positive attitudes towards radiological risk should include at the individual and/or organisational level:
- A questioning attitude (e.g. did I do what I could to reduce doses? is the management committed to the introduction of new technologies to reduce doses or prevent accidents? ...);
- Openness and transparency (e.g. open to changing habits, reporting mishaps, explaining radiation protection options, …);
- Commitment to dose reduction (e.g. appropriate individual behaviour in the presence of radiation sources, willingness to invest in protection measures, …).

The assessment of ALARA culture will usually look at elements such as: what is the strategy adopted to reduce exposures, how is it applied, what are the responsibilities given to the management in this specific field of RP, what are the attitudes and behaviour of the various stakeholders.

Commitment from all stakeholders is needed to search for dose reduction options. The elements contributing to the culture might differ among different stakeholders. However, one common basis is the knowledge of the dose-effect relationship and the search for an acceptable level of risk according to the characteristics of the exposure situation taking into account socio-economic aspects and the evaluation of other risks.

Decisions made in the ALARA process may often be based on qualitative elements that can lead to different interpretations. In order to achieve coherent and sound decisions, guidance must be given on the interpretation of the ALARA principle.

1.3 Role of stakeholders

Different categories of stakeholders can be identified depending on the exposure situation. In general, one can identify the following roles and responsibilities in the implementation of an ALARA process:

Competent authorities are responsible for including optimization requirements in national legislation according to international safety standards and regulations (from IAEA and EC). They set the regulatory

objectives for ALARA. Moreover, they should establish and apply appropriate methodologies for the verification of ALARA implementation and to issue recommendations and take enforcement actions if required, taking into account that ALARA is an obligation of means. Regarding the relationship with the public, they should provide transparent information and also facilitate public involvement in the decision-making processes.

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

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

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

Professional associations and ALARA Networks have a role in the dissemination of ALARA culture among their members, for example by providing a forum for exchange of knowledge and experience and providing detailed radiation protection guidance or protocols specific to their field of activities, etc. (IRPA, 2014)

Exposed workers are responsible for applying ALARA procedures properly after having received appropriate training. They should have a positive attitude towards dose reduction for themselves as well as their colleagues. They should not only follow given guidelines and protocols but also identify and report possible problems, as well as applying the required corrective measures. They should participate in the continuous optimization of radiation protection by proposing improvements and providing practical feedback.

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

References

EC, 2013. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom

ICRP, 1990. Optimization and Decision Making in Radiological Protection. ICRP Publication 55. Ann. ICRP 20 (1).

ICRP, 1991. 1990 Recommendations of the International Commission on Radiological Protection. ICRP Publication 60. Ann. ICRP 21 (1-3).

IRPA, 2014. IRPA Guiding Principles for Establishing a Radiation Protection Culture, IRPA, 2014 Edition.

2 ELEMENTS OF THE ALARA PROCESS IN PLANNED EXPOSURE SITUATIONS

This chapter deals with specific aspects in the application of the ALARA process in planned exposure situations for workers, patients and for the public in different fields.

2.1 Occupational exposures in the nuclear, industrial and research fields

2.1.1 Characteristics of exposure situations

Occupational exposures in the nuclear field occurs during plant operation but originates mainly from maintenance work during plant outage. This kind of work is usually performed in a complex environment where the risk of external exposure and contamination is present, and where the sources of exposure on the work floor are multiple.

In the field of non-destructive testing, the main occupational exposure is due to industrial radiography and associated gammagraphy apparatus. The environment where the exposure situation occurs can vary a lot (outdoor or indoor work place, in many cases within a narrow space or complex environment). Industrial radiographers working in a nuclear power plant setting also need to consider occupational exposure originating from the plant environment.

Other activities in the industrial field giving rise to occupational exposure include, calibration, industrial irradiation, manufacture of radiopharmaceuticals and other activities using radioactive sources such as moisture gauges and gamma-densitometers, thickness or level gauges, ionizers, etc.

In the research field, occupational exposures are linked mainly to activities in laboratories (usually through the use of unsealed sources of radiation or X-ray generators), in research reactors where particle accelerators are used for research on matter or for the manufacture of radionuclides, or indeed in the indoor or outdoor environment.

2.1.2 Stakeholders and specific ALARA structures

Where the presence of radiation is central to the process, as in the nuclear industry, there are usually specific radiation protection organizations responsible for the management of occupational exposures, as well as dedicated structures for the performance and evaluation of ALARA analysis.

In the nuclear sector, for example, the main actors associated with the ALARA process are (see Figure 3):

ALARA analyst(s): This is the person in charge of the ALARA analysis. It can also be a team of persons, with various professional skills (radiation protection, professionals of the work to be analysed, …).

Planner and the facilities expert: they help to clearly define the work and will provide the ALARA analyst with information on the working environment. The planner will also provide input on the resources (human, financial, technical, …) that can be made available.

Worker or operator will provide the ALARA analyst with finer details of the work and the working conditions (confined spaces, lighting conditions, ventilation, non-radiological risks….) that can define boundary conditions for the dose reducing measures.

Communications with the planner and operator also provide information on the technical aspects of the site such as geometry, materials and technical limitations. Knowledge of the site history may also be important for a better understanding and interpretation of the radiological characteristics of the site.

The radiation protection officer provides the analyst with the radiological characterisation of the site. This information is gathered through radiation measurements, for example of the levels of surface and air contamination, and beta, gamma and neutron dose rates at different locations. More detailed information may also be needed, such as the isotopic composition of the sources, etc.

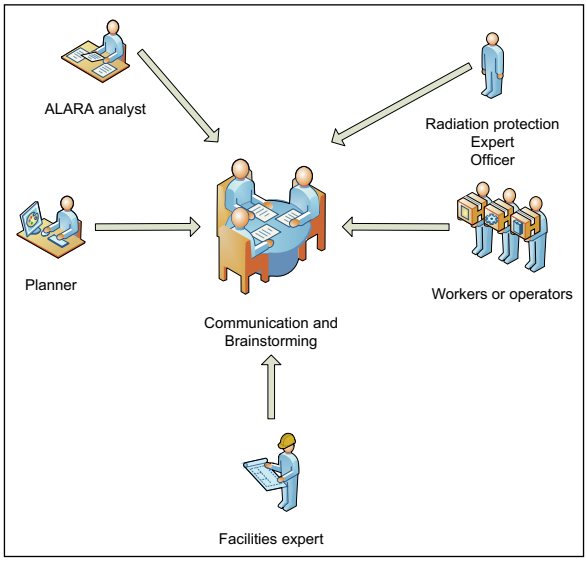

Figure 3. – Different contributors in the definition of the problem in the ALARA process.

Specific structures in the organization can be created in order to gather the stakeholders in the ALARA analysis process periodically.

For example:

- ALARA Committee; this structure is very often found in nuclear power plant organizations. Such a committee is generally chaired by a representative from top management and members are representatives of the various domains of expertise in the ALARA process. The ALARA Committee can be consulted to validate ALARA plans, procedures, pre/post-job ALARA evaluations, etc.
- ALARA engineering group or Job specific ALARA group: to facilitate the practical implementation of the ALARA programme, a multi-disciplinary group of radiation protection professionals and workers can be set-up for specific activities or jobs that may require specific attention and optimization. This practice is also quite common in the nuclear industry.

It is also recommended to develop formalised ALARA Programmes that set out a general strategy for dose reduction and optimization, often by defining targets and objectives for the short, medium and long term. Such ALARA Programmes should be validated at the top management level of the organisation, which by doing so demonstrate their commitment to radiation protection and optimization.

Radiation Protection professionals (Radiation Protection Managers/Experts/Officers/…) should be responsible for the practical implementation of the ALARA Programme. Their responsibilities are important and they often have the competence and authority to:

- Develop methods and procedures for implementing the ALARA process;
- Develop and deliver radiation protection training;
- Analyse work conditions leading to exposure and propose action plans;
- Ensure the ALARA programme is followed;
- Gather and analyse feedback for continuous improvement.

2.1.3 The specificities of protective actions

Dose reducing measures can be identified in a brainstorming session with the different stakeholders by examining the basic methods for exposure control:

- Reducing the source activity or dose-rate;
- Reduction of the exposure time;
- Increasing the distance to the source;
- Increasing shielding;
- Using personal protective equipment.

The fact that the identification of the different dose reduction actions takes place in a brainstorming session with the planner, workers and radiation protection expert is important because this stimulates the investigation of radiation protection solutions that otherwise would be missed. Listing the dose reducing solutions according to the basic methods for exposure control provides a structure and also stimulates the search for solutions in each category.

The identification of protective actions can be facilitated by the use of a checklist of typical actions. Specific checklists have been developed by the nuclear industry, some of them to be used at the design stage of the facility, others for the analysis of jobs. Examples are provided in Appendix C.

The ISOE network has provided a specific report on the application of work management principles as a contribution to the optimization of radiological protection in nuclear power plants (ISOE, 2009) This report includes not only advice for specific protection actions, but also on the whole work-management aspect (organizations, structures, education and training, …)

A few examples of typical actions which can be implemented in the case of occupational exposures in the nuclear industry are given below. Some of them apply also for occupational exposures in the industry or research field

Reducing the source

Move or remove sources

The first action is to question if there is the possibility to simply move or remove the source from site. This can be achieved by (temporarily or not) removing contaminated, activated parts from the work area or removing the component to be worked on from an area with high dose-rates. Unfortunately, the last is often the least practicable option.

Selecting materials at the design stage of installation

Proper material selection at the design stage of an installation can lead to a reduction in corrosion, erosion or activation resulting in a lower distributed radiation hazard in the work area (e.g. limiting alloy with cobalt that might activate)

Maintaining water in circuits

Whenever possible, water should be maintained in the circuits or large vessels (like steam generators) to reduce the ambient dose rate. This sometimes requires that the schedule of tasks is reorganised according to the water movements in a facility.

Decontamination

Several types of decontamination exist: mechanical, chemical or a mixture of the two. Mechanical decontamination techniques include: use of peelable paints, use of ultrasonic cleaning, and adhesion for a weakly fixed contamination. The objective of chemical decontamination is to dissociate the liaison between the surface of the materials and the contaminant. Several processes can be used, to be adapted to the size of the components to be decontaminated (small portion of a circuit to full system decontamination).

Introduce or improve shielding

The introduction of well-designed shielding will reduce the dose rate at the working place. It is clear that the size and shape of the shielding will depend on the energy and type of the radiation. A good knowledge of the energy spectrum or isotopic vector is therefore a prerequisite for an effective shielding design.

Shielding should be incorporated in the original workplace design where possible in order to avoid cumbersome mounting and subsequent removing of temporary shielding, leading to potential exposure.

The retrospective introduction of shielding will in most cases also lead to additional exposures that must be included in the complete dose evaluation.

Reducing the exposure time

Tool efficiency

The design, selection and use of more time-efficient tools can lead to a considerable reduction in exposure times. As an example, pneumatic scissors can be more time efficient than a grinding disc for cutting operations in decommissioning. Designing and implementing dedicated tools for the maintenance of certain components can also lead to a significant time gain by reducing the exposure time.

Ergonomics
Improving the ergonomics of the work environment (good lighting, freedom of movement, avoiding awkward work positions, etc.), can shorten the exposure time.

Component design taking ALARA into consideration from the start can avoid a lot of dose in maintenance activities. The technical design of components that need servicing in the future can be optimised so that maintenance times are reduced. A good example of this are valves designed for Sizewell B that reduce the time needed for unbolting and rebolting during inspection or maintenance.

Where possible the installation of fixed access platforms for maintenance will also reduce exposure time in maintenance by avoiding the construction and dismantling of scaffolding for maintenance purposes.

Training
An effective technique to reduce the exposure time is training of the personnel. The training is performed on mock-ups of the installation where the trainees encounter the same situations expected in the workplace.

Another important aspect is worker awareness of the radiation risk. This can be achieved by providing the worker with information on the dose=rate distribution in the work area before the start of the operation. Experience shows that an informed worker will avoid unnecessary lingering at positions with increased dose rates.

The work sequence also needs care and due consideration as in certain cases the unnecessary presence of operators in the working area during particular steps in the work can be avoided.

Increasing the distance
Remote handling/robotics
An effective but often expensive way of reducing exposures is to introduce remote handling equipment or robotics. Experience suggests that this is mostly suitable for high dose-rate environments. Due care and attention must also be given to doses that can arise during the maintenance or repair of this equipment.

Long handling tools
A simpler method is the introduction of long-handled manual tools. This can reduce the dose rate to which workers are exposed but sometimes, if proper training and testing is not provided, it can lead to an increase in exposure time. A good balance must therefore be found in order to achieve dose reduction.

In general, a good knowledge of the location and strength of the most important sources will enable the worker to maximize his distance.

Use personal protective equipment
In all cases collective protection is preferred to personal protective equipment. The use of personal protective equipment is not a panacea and should also be considered in an overall ALARA approach. For example, if a lead apron will slow the movements of workers and thus increase the exposure time, it may be better to use a fixed or mobile lead screen. In the same way, the use of respiratory protective

equipment recommended in case of airborne contamination can lead to thermal stress for workers (over-heating). The risks and benefits should always be considered together to achieve the best ALARA approach.

2.1.4 Follow-up, feed-back experience and performance evaluation

2.1.4.1 Operational dose follow-up and collection of feed-back experience

A thorough dose follow-up scheme of occupational exposures needs to be put in place to collect and analyse feed-back experience to check whether the ALARA process has met expectations. This relies on appropriate dose monitoring usually using electronic dosimeters for external exposure and specific follow-up when risks of internal exposure are present. Such schemes are particularly essential for repetitive jobs where analysing the job feedback and implementation of the return of experience can lead to dose reduction.

The questions that need to be asked on a continuous basis are:

- Are the doses in accordance with the predictions?
- If discrepancies are present, what is their cause?
- Are additional protective measures needed based on the comparison of predicted and measured dose?

It is important to record the work and the dose performance and evaluate the result of the complete ALARA process. This can be done in feedback reports that are discussed in feedback meetings and later stored with remarks in ALARA feedback databases. These ALARA databases can then be drawn upon for future similar operations.

Figure 4 illustrates a whole ALARA process from the analysis of work to feed-back experience, with the role of the various stakeholders

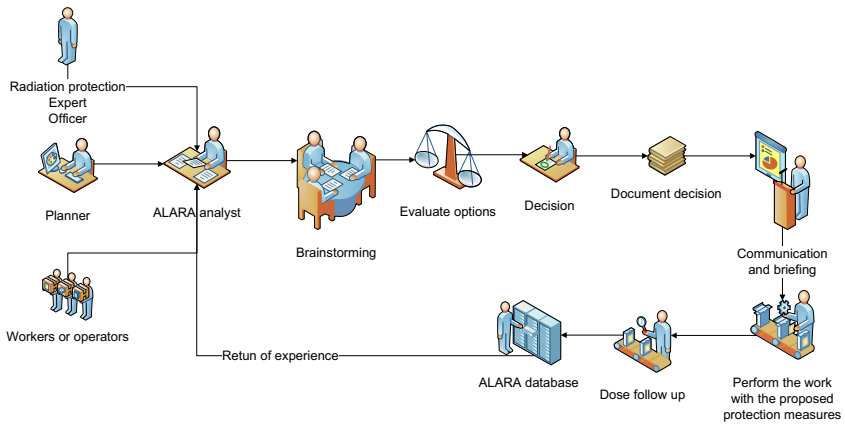

Figure 4. – ALARA process including dose follow up and return of experience.

2.1.4.2 *Evaluation of performance*

ALARA Performance Indicators

To track and improve the performance of radiological tasks, "ALARA performance indicators" are tools to assist the management in focusing priorities to establish excellence in radiation protection. ALARA performance indicators can be very specific to an organization or even an installation, so there are no common rules or general recommendations for their definition. In all cases, the ALARA performance indicators, their status and goals should be documented and recorded.

An international survey performed by the ISOE network in 2015 for nuclear power plant utilities and regulatory bodies on this topic showed a great variety in the number and type of ALARA performance indicators. However, some common categories related to occupational radiation protection have been identified:

- Collective dose;
- Individual dose;
- Source term management;
- Radiation protection management;
- Personal contamination events;
- Other radiation protection events;

Inspections

Inspections are performed by regulatory authorities. They can be part of an authorization procedure or be performed regularly during the operation stage of facilities. The evaluation of the use of the ALARA principle is generally part of the inspection on radiation protection. This will be a harmonized practice in Europe with the implementation of the 2013/59/Euratom Directive that clearly introduced the ALARA principle as part of a radiation protection system (article 5).
It should be remembered that ALARA is an obligation of means and not of results. Inspections should, therefore, focus on those "means" (organisational, financial, technical, ...) used to optimise protection.

Audits in nuclear facilities

The auditing system can be internal at the plant level, or if relevant, organised at the corporate level to obtain a global picture of all the plants belonging to the utility. Internal audit programmes should include verification of compliance with national regulations as well as with the utilities' internal rules and objectives.

Specific attention should be devoted to audit regularly the content, organization and implementation of the ALARA Programme of the facility. The main domains to be addressed by this type of audit are the following:

- On-site radiation protection organization for ALARA;
- Organization and management of the ALARA Programme;
- Work planning and organisation;
- Factors to be addressed in work preparation ("radiation protection in the field");
- Work implementation and follow-up;
- Management of feedback.

External audits, such as OSART (Operational Safety Review Team) missions organised by the IAEA or Peer Reviews organised by the WANO (World Association of Nuclear Operators), are also very useful

as they bring in experts from other plants, ensuring the independence of the audit while contributing to information and experience exchange between plants:

- OSART missions are carried out at the request of the relevant IAEA Member State, and review all items essential to operational safety. A mission can be tailored to the particular needs of a plant, e.g. radiation protection and ALARA implementation. Essential features of the work of the OSART team members and their plant counterparts include the comparison of plant operational practices with best international practices and the joint review of ways in which operational safety can be enhanced.
- Peer reviews organised by the WANO aim to help WANO members compare their operational performance against best international practice through an in-depth, objective review of their operations by an independent team from outside their utility. The review, carried out at the request of the plant, is conducted by an international team consisting of staff from other nuclear power plants, i.e. peers of the staff of the station reviewed. The team examines the plant's performance in key areas in accordance with specific performance objectives and criteria. WANO peer reviews give members an opportunity to learn and share the best worldwide insights into safe and reliable plant operation, and thereby improve their own performance.
- Less formal reviews and benchmarking have also been organized between utilities. This organization is easier for the NPP to manage and can also provide useful initial insights. These kinds of reviews are often focused on specific topics and do not cover all the aspects of a NPP as an OSART or WANO would review.

2.1.5 Education and training

To adhere to the ALARA process, all individuals involved in radiation protection should understand the ALARA approach and its purpose. Education and training (E&T) are widely recognized as key components of an optimization programme. Traditional approaches to defining education and training state that "education" refers to the initial training, while the continuing maintenance of competencies is referred to as "training". Education is mainly provided by universities, colleges, schools etc. leading to the legal recognition of the diplomas they deliver. Training is the task of "training providers" such as training departments embedded in companies, research centres, safety authorities, and so on. Historically, these apply *a priori* to planned exposure situations, but E&T concepts have somehow diffused to other exposure situations.

In all case, the E&T should be adapted to the role, responsibilities and the perspective of the individuals and would be different for a manager compared to a radiation worker, for example.

The EU BSS (EC, 2013) has formally defined the "necessary knowledge, education and training" of the individuals having radiation protection responsibilities, i.e. the licensee (employer), the Radiation Protection Expert, and Radiation Protection Officers as well as workers. Prior to this latest BSS, there was considerable variation in the approaches of European countries to education and vocational training arrangements for radiation protection. The EUTERP (http://www.euterp.eu) and ENETRAP (http://enetrap.sckcen.be) projects helped in defining and agreeing on the role of the individuals and drafted an harmonized approach in Europe through the BSS.

The ultimate goal of training is better radiation protection overall and, like other protection options, training should be optimised to deliver the maximum benefit without being unduly expensive or time-

consuming, i.e. it should be both effective and efficient. Assessing the effectiveness of training traditionally relies on written tests (knowledge and understanding tests) at the end of training courses. Practical skills can be directly tested using practical assessments, made under the observation of the trainers, although the quantitative marking of performance is not straightforward: ideally, the effectiveness of training should be demonstrated by tangible improvements in radiation protection. Work-related benchmarks and use of indicators are possible but a better option would be to find a means of assessing individual attitudes to radiation protection, ideally before and after training.

Issues for situations other than planned exposure situations.
Understanding and implementing the ALARA principle is not only based on academic qualifications and RP training courses. It also relies upon acquired knowledge, experience, skills and competencies. The sum of the academic knowledge and the experience gained in the field contribute to the "ALARA culture" of the individuals. The notion of ALARA culture is even more general than E&T as it can concern all exposure situations. Furthermore, "soft skills" such as leadership and communication should also be considered for persons who have roles in promoting radiation protection and ALARA culture. Professional associations and societies, and ALARA networks, also play a key role in the dissemination of radiation protection and ALARA culture.

2.2 Occupational and patient exposures in the medical field

Today, medical diagnostic and therapeutic procedures constitute by far the most significant man-made source of radiation exposure to the general population. This section deals with specific aspects regarding the ALARA process in the medical field (radiology, nuclear medicine, and radiotherapy) for workers, patients and the public. The role of the stakeholders involved in this ALARA process is presented as well as techniques for keeping the exposures as low as reasonably achievable for the patients and the personnel participating in medical procedures with ionising radiations.

2.2.1 Stakeholders in the medical field

A stakeholder in the medical field is the person who is (or should be) entitled to have an interest in radiation protection in medicine. Regarding the ALARA principle, the stakeholders who could play a major role are:

- Medical doctors, medical physicists, radiographers and other medical and paramedical staff;
- Manufacturers and suppliers, staff undertaking installation and maintenance;
- Hospital/facility directors;
- Legislators and authorities and
- Patients.

More specifically:

a. *Medical doctors* should have the required training on ALARA implementation in order to ensure that the patients will acquire the best diagnostic or therapeutic result whilst the risk associated with their exposure to radiation will be kept as low as reasonably achievable.

b. *Medical physicists* have a critical role not only in the establishment of optimized diagnostic and therapeutic procedures but also in the supervision of their implementation and the evaluation of

their effectiveness. Moreover, they have the responsibility to provide the personnel with the information and guidance required to keep their competence at appropriate levels.

c. *Radiographers* should have adequate training on radiation protection and have an ALARA attitude. Moreover, they should be able to identify procedures that could be improved as far as the patient exposure is concerned and to report appropriately to the medical doctors or the medical physicists.

d. *Hospital/facility directors* must be aware of the ALARA concept and they should support optimization activities through the provision of the required resources (radiation protection equipment, continuous training, etc.) Their commitment to ALARA must be clear and sound in order to inspire the personnel.

e. *Manufacturers* of medical equipment should ensure that the ALARA principle is taken into account in the design of new ionizing radiation systems by providing equipment with appropriate technical specifications and operation modes as well as optimized clinical protocols.

f. *Legislators* must be well aware of the ALARA principle, since they have the responsibility to introduce appropriate provisions in the national legislation to promote ALARA implementation and the related culture. Moreover, *regulators* should be adequately trained to ensure that ALARA is appropriately implemented by the stakeholders and in accordance with the relative legislative requirements.

g. Well-aware patients can also play a significant role in ALARA implementation, by questioning and applying appropriate pressure either individually or through their organizations to the other stakeholders involved directly or indirectly with medical exposures.

2.2.2 Education and Training in the medical field

It is widely recognised that a high standard of education and training (E&T) is a key factor in radiation protection in medicine for reducing patient doses while maintaining the necessary level of quality for diagnostic and therapeutic procedures. International and European organizations such as ICRP, IAEA, the World Health Organization (WHO), the European Federation of Organizations of Medical Physics (EFOMP[5]) and the European Commission (EC) have recognised the importance of E&T and published numerous documentations on this theme.

IAEA's Radiation Protection of Patients (RPOP) website provides information and training materials on the safe use of ionizing radiation in medicine (RPOP). It covers a wide range of ionizing radiation applications in medicine (radiology, radiotherapy, nuclear medicine, interventional radiology, etc.) and intends to:

- Help health professionals achieve safer use of radiation for the benefit of patients;
- Answer specific questions of patients and the public regarding radiation protection during diagnostic or/and therapeutic procedures.

The requirements for E&T of medical professionals have been strengthened in the revised European BSS (EC, 2013) and the introduction of a course on radiation protection in the basic curriculum of

[5] https://www.efomp.org

medical and dental schools was proposed to be made mandatory. New legal provisions require that Member States shall ensure that mechanisms are in place for the timely dissemination of appropriate information relevant to radiation protection in medical exposure particularly from lessons learned from significant events.

2.2.3 Elements of the ALARA process for occupational exposure in the medical field

The occupational exposures from medical applications of ionizing radiation depend on the type of the procedures as well as on the techniques applied, especially in the case of interventional radiology and nuclear medicine. Appropriate training, an ALARA attitude and the implementation of dose constraints can effectively result in decreased occupational doses.

a. Radiology

Doses to the personnel from diagnostic X-ray procedures are expected to be low. However, the risk increases for the medical and paramedical personnel who participate in diagnostic procedures in which real-time imaging is performed. Some measures that should be taken to keep occupational doses as low as reasonably achievable include (RPOP):

- Appropriate design of facilities and imaging equipment including the designation of workplaces as controlled and supervised areas;
- Individual radiation monitoring;
- Appropriate use of personal protective devices (lead lined aprons, leaded glass eyewear, thyroid shields, protective screens, etc.);
- Implementation of optimized procedures during medical examinations.

b. Interventional radiology/cardiology

The need for medical and paramedical personnel to stand close to patients during interventional procedures results in their increased exposure to scattered radiation. Moreover, there can be an additional risk of exposure to the primary beam due to the complicated manipulations which are required during these procedures. The following measures can effectively reduce the related exposures:

- Minimization of screening time and of the number of images;
- Using pulsed rather than continuous exposure systems;
- Use of available patient dose reduction technologies;
- Proper use of collimation;
- Keeping hands out of the beam;
- Positioning of personnel in a low-scatter area;
- Maintaining awareness of body position relative to the X-ray beam;
- Horizontal X-ray beam: the operator and the staff should stand on the side of the image receptor;
- Vertical X-ray beam: the image receptor should be above the table;
- Use of protective shielding;
- Wearing adequate protection (Protective well-fitted lead apron, Leaded glasses);
- Wearing personal dosimeters and being aware of the dose received.

c. Nuclear medicine

In nuclear medicine, the use of unsealed radioactive sources for diagnosis or treatment is related to higher occupational doses. The measures that can be taken for the reduction of occupational doses include (RPOP):

- Appropriate design of facilities;
- Appropriate designation of workplaces in control and supervised areas;
- Individual, area and contamination monitoring;
- Appropriate use of personal protective devices and tools;
- Following the local rules and procedures for safe handling of radiopharmaceuticals;
- Written procedures regarding the handling of possible accidents and the removal of contamination.

d. Radiotherapy/brachytherapy

The measures taken (shielding, interlocks, etc.) in radiotherapy facilities due to the high output radiation sources used significantly reduce the possibility for occupational exposures. However, some points which have to be underlined are:

- Ensure that the irradiation has been terminated before entering the treatment room;
- Be aware of the exposures due to neutron activation for therapy beams with energies > 15 MV;
- Development of appropriate emergency plans with appropriate personnel training on their implementation.

2.2.4 Elements of ALARA process for patient exposures in the medical field

2.2.4.1 Justification of medical exposure

Every medical exposure has to be justified. When alternative techniques with the same diagnostic or therapeutic result are available, they should be preferred. The use of appropriate referral guidelines is critical. These guidelines should be evidence-based and regularly updated in order to strengthen the appropriateness of the medical exposures. Local conditions should always be considered for the feasible and sustainable implementation of referral guidelines. Therefore, there is a need to complement the guidelines with other strategies such as awareness, audit and education.

Special criteria should also be developed for the justification of health screening programmes for asymptomatic populations and for medical imaging of asymptomatic individuals who are not participating in approved health screening programmes.

The introduction of information technology solutions, such as decision support tools is expected to facilitate the integration of referral guidelines into the daily clinical workflow. To be effective, these tools must be available and freely accessible at the point-of-care.

In every case, the introduction and application of the "3A's" (awareness, appropriateness and audit), is likely to facilitate and enhance justification in practice.

2.2.4.2 Dose reduction techniques for the patient

Some methods for the reduction of patient doses from diagnostic and therapeutic procedures are presented below:

a. CT examinations

Techniques to allow dose reduction during CT scans without or with a minimum loss of image quality (EMAN, ICRP 105, ICRP 121) include:

- Improved detector technology (receptor material, detector electronics, scatter reduction);
- Adaptive collimation to reduce over-ranging;
- Dose modulation and automated exposure control;
- Adaptive filtering of raw data;
- Iterative reconstruction of raw data, etc.

Additionally, the optimization of scan protocols should be considered. Specific CT protocols should be chosen so as to provide the clinically required image quality while aiming at a dose as low as reasonably practicable. This involves setting up standardized protocols that use individual adaptation of the scan parameters and exposure settings to compensate for individual variations in body size. Such adaptations are especially important in children where unadjusted protocols may lead to a radiation exposure with a substantial and unnecessary increase in radiation-induced cancer risk. Adaptations are also necessary for obese patients in order to maintain sufficient image quality.

Setting-up a "core team" consisting of a specialized CT radiologist, a CT radiographer and a qualified medical physicist is recommended to ensure the best compromise between image quality and patient dose. Moreover, appropriate training of referring physicians and CT personnel is considered necessary for the proper management of scan indications, protocols, and patient doses.

Particular attention should be paid to dose reduction actions as part of the optimization process when purchasing a new CT scanner. In this respect, a medical physicist should be involved in the steps of procurement, commissioning, quality control tests etc.

b. Interventional Radiology/Cardiology

Certain actions can reduce the exposure of the patient during interventional procedures, such as (EMAN; ICRP 2010; ICRP, 2013; ICRP, 2013a):

- Use of appropriate imaging equipment;
- Use of all available information to plan the interventional procedure;
- Minimization of the screening time and of the number of images;
- Use of pulsed rather than a continuous beam;
- Use of good imaging-chain geometry - Maximization of the distance between X-ray tube and the patient and minimization of the distance between patient and image receptor;
- Limitation of the use of electronic magnification;
- Use of available patient dose reduction technologies (last-image-hold, pulsed fluoroscopy and low frame rate;
- Continuous monitoring of patient doses and use of trigger levels;
- Limitation of the irradiation field to the area of interest (appropriate use of collimation);
- Avoid steep gantry angles (steep oblique and lateral positions) when possible;
- Keep unnecessary body parts out of the X-ray beam.

Paediatric cardiology procedures are often more challenging, time-consuming, and may require multistage procedures resulting in high patient doses. Patient doses from these procedures can be reduced by the use of: dedicated radiographic protocols with tighter collimation, pulsed beam frame rates of 25 to 30 frames/s, and cine frame rates of 25 to 50 frames/s.

c. Nuclear medicine
Optimization of patient protection in *diagnostic nuclear medicine* can be accomplished through (RPOP):

- The administration of the optimum amount of radiopharmaceutical. Patient factors such as age, disease, and size should be considered in the optimization of the examination;
- Equipment must be operated within the limits and conditions established in the technical specifications and in the licence requirements;
- The data acquisition conditions (collimator, energy window, matrix size, acquisition time, etc.) should be chosen such that an image of optimum quality is acquired;
- For dynamic studies, the number of frames, the time interval and other acquisition parameters should be adequate to obtain optimum quality of image sequence;
- The patient should be fully informed about the examination and subsequent precautions, as appropriate.

In *therapeutic nuclear medicine*, the optimization of procedures requires an accurate and precise prescribed dose to the target tissue or organ. The optimum patient dose is achieved through individual dose planning and calculations based on uptake measurements and the volume of the treated organ as well as on the correct determination of the amount of activity to be administered.

2.2.5 Follow-up and performance analysis

2.2.5.1 Follow-up of occupational exposures

Routine individual monitoring is usually based on personal dosimetry. Occupational exposures of Category A workers must be monitored on a regular basis while those of category B workers should also be monitored if this is considered necessary. The monitoring results must be available to the competent authorities, to the health service undertaking, to the exposed worker, and, for Category A workers, to the approved medical practitioner or approved occupational health services.

If routine monitoring is not possible, dose assessment could be based on area monitoring data, occupancy data, numerical methods, etc. When daily monitoring is required (e.g. interventional radiology), an appropriate direct reading dosimeter should be used in addition to the official one.

Individual monitoring results must be recorded appropriately. Record keeping is an essential part of the monitoring process. Apart from demonstrating (the degree of) compliance with legal regulations (dose limits) and locally established dose constraints, record keeping may also be used to demonstrate the effectiveness of ALARA, to evaluate trends in exposure, the applied practices and the radiation protection system as well as to provide data for epidemiological and research studies, etc.

In 1997, the European Commission initiated the European Study on Occupational Radiation Exposure (EC, 2009; ESOREX) in which the objectives were:

- To provide the European Commission and the national competent radiation protection authorities with reliable information on how personal radiation monitoring, reporting and recording of dosimetric results is structured in European countries;
- To collect reliable and directly comparable data on individual (levels of individual personal radiation doses to workers) and collective exposure in all occupational sectors where classified workers are employed (nuclear fuel cycle, medical sector, industry in general, research and education, and natural sources), and the trends and developments of these doses over a period of several years.

The results of this study as available on the ESOREX Platform can be used to improve ALARA culture amongst radiation workers.

2.2.5.2 Follow-up of patient exposures

Patient doses from the diagnostic or therapeutic procedures must be recorded and evaluated.
In this respect, radiology and nuclear medicine facilities should establish local Diagnostic Reference Levels (DRL) as part of the optimization process for patient doses. DRLs have to be reviewed on a regular basis and compared to the national DRLs. If their values exceed systematically the corresponding values of the national DRLs, an investigation is required to identify the reasons and take the required corrective actions such as the optimization of the applied examination protocols.

The DRL values in various countries around Europe are provided for comparison purposes in the European Radiation Protection Report 180 (EC, 2014). The report provides useful data regarding medical exposures which were collected during Dose Datamed 2 (DDM2) project. In the framework of the project a study was conducted through web-based questionnaires, with specific Excel-forms for detailed data collection. The questionnaires were distributed to all EU member states, EFTA countries and some other European countries. Frequency and effective dose data were collected for the "Top 20 procedures" (Top 20 approach) defined in the Radiation Protection Report 154 (EC, 2011) in all countries, while comprehensive data for all x-ray procedures and nuclear medicine (NM) procedures were collected in a few countries. Both sets of data were used to estimate the overall frequencies and collective effective doses to the European population, as presented in the published report.

2.2.5.3 Clinical audits in the medical sectors

Clinical audits may be defined as: "the systematic and critical analysis of the quality of clinical care. This includes the procedures used for diagnosis and treatment, the associated use of resources and the effect of care on the outcome and quality of life for the patient." (IAEA, 2010). They involve evaluation of procedures, data, documents and resources to check performance against related standards. Although radiation protection aspects are only one part of the clinical audit process, the audit report can be a very useful tool for the evaluation of ALARA implementation. The general principle of audits requires that the auditors have to be independent of the service or process to be audited.

Clinical audits can be either internal or external. Internal audits are carried out within a certain health care institution by auditors from other subunits or departments of the institution.

Emphasis has recently been placed on external audits, in which the auditors are totally independent of the institution being audited (IAEA, 2007). Their value lies mainly in providing a broader peer-reviewed perspective, and removing the possible inability of internal auditors to recognize, in their own environment, the weaknesses and limitations that may involve long-standing or routine practices (EC, 2010).

2.2.6 Elements of the ALARA process for comforters and carers in the medical field

Comforters/carers are normally adults over the age of 18 years who support or help (not as part of their employment) the patients during an examination or therapy that makes use of ionizing radiation.
In most cases, the doses received by the comforters/carers (when their involvement is justified and the appropriate radiation protection measures are taken) are expected to be low.

However, in terms of ALARA, specific actions may be required, such as the provision of appropriate information regarding the doses they are expected to receive and the associated risks as well as the protective measures to be taken (procedures, protective clothing, etc.) (EC 1998, ICRP 2004).

In the case of patients administered with radiopharmaceuticals, the significant proportion of a comforter/carer exposure usually occurs following the departure of the patient from the hospital/clinic due to patient retained radioactivity. Therefore, it is of great importance that both the comforter/carer and the patient be provided with appropriate written instructions on the measures to be taken for the minimization of the related exposures.

2.3 Public exposures from planned activities

In normal operations, public exposure due to planned exposure situations usually arises from the release of radioactive effluents into the environment (gaseous or liquid effluents). Discharge limits have traditionally been set at levels designed to limit the estimated radiation dose to a member of the public to no more than a specified value (e.g. a public dose constraint)

Usually a less formal approach than that used for occupational exposures is adopted for the evaluation of the various options to be implemented to reduce the amount of effluent discharge. This is generally because there is more focus on "minimisation" of exposure to the public taking into account the best available technology, than for "optimization" balancing cost and effectiveness of the processes.

2.3.1 Stakeholders to be involved in the process

The national regulatory authority is in charge of setting authorised limits for the release of effluents - different limits may apply, depending on the radionuclides and the type of facility. As part of the safety assessment (initial or updated), the licensee shall demonstrate that the installation will comply with the legal requirements. The regulatory authority, supported by research agencies or laboratories, can also recommend or require environmental monitoring, sampling and analysis programmes.

In some situations, representatives from the public may be involved when drafting or updating the safety assessment. Such involvement was not considered at the beginning of the use of nuclear energy but is becoming more frequent since the adoption of the Aarhus convention (Aarhus, 1998; international agreement signed in 1998 by 39 States). The convention provides for the right for

everyone to receive environmental information held by the public authority, the right to participate in environmental decision-making and the access to justice.

Other stakeholders namely designers, suppliers, technical support organizations, international organizations etc. can also be involved in the process.

2.3.2 Initial Dose Assessment

Discharge limits for radioactive materials are generally set on the basis of ensuring that the effective dose to a "representative person" (ie public) does not exceed a specified value, normally set in the range 0.1 to 1 mSv/y. Because it is not possible to assess the dose to each member of the public, it is necessary to define a representative individual, that is to say an "individual in the population group most highly exposed (to the radioactive substances contained in the releases from the facility) and whose radiation dose represents the doses received by such a population group (ICRP, 2006)[6].

The process for initial dose assessment (1st step of the ALARA approach) is presented in Figure 5 (inspired from EPA, 2002).

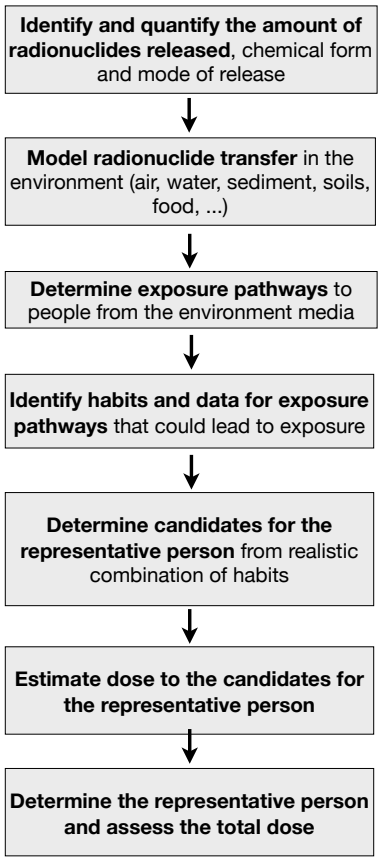

Figure 5. – Generic dose assessment process for public exposure from planned activities.

[6] The representative individual is equivalent to and replaces the previous term of « average member of the critical group ».

The process described above is quite general and will need adaptation for specific cases, such as assessment of public exposure outside building containing a source (e.g. irradiators, X-rays machine).

The dose assessment requires assumptions to be made regarding the behaviour of radionuclides in the environment and the habits of people who may be exposed. One approach is to make an assessment using simple cautious assumptions to ensure that the dose is very unlikely to be underestimated (using generic representative persons and associated generic behaviour or habit data). An alternative approach is to make a realistic or best-estimate assessment of doses using knowledge and data for known population groups around the site of interest (i.e. a site-specific assessment). To implement the ALARA process properly, the aim should be the latter, i.e. to estimate public doses realistically, and avoid overconservative assumptions and overestimations.

2.3.3 Identification of protective actions and decision-making process

At the design stage.
If the calculated dose to the representative individual is above the dose constraint, actions shall be taken to reduce it. Reducing public exposure should be achieved mainly by acting on the releases:

- Treating the effluents before release, for example by mechanical filtration, ion exchange, evaporation and chemical precipitation;
- Reduce and minimize the volume of effluents so as to reduce the levels of radioactivity discharged to the environment;
- Delaying the release of effluents to allow reduction of activity through radioactive decay;
- Change in the discharge arrangement: localization of the release point to allow better dilution (discharge pipes to surface waters, higher stack).

At the design stage or when in operation.
If the calculated dose to the representative individual is below the dose constraint, the optimization process should still be applied. The facility operator, in consultation with the regulatory and other stakeholders where appropriate, can determine if lower levels of discharges (and resultant calculated doses) are reasonably achievable. For example, the dose constraint at the beginning of operation of many nuclear power plants was 1 mSv/y to any member of the public. As years go by, this figure has been strongly reduced, generally to currently 0.1 mSv/y. Indeed, strong efforts have been made to keep the radioactive releases and the resulting exposition ALARA – the actual dose is generally in the order of a few µSv for the most exposed individual.

Selecting of the most appropriate protective action requires radiological, environmental, societal and economic aspects to be balanced. For example, there would be no overall benefit to the environment if, as a result of a new abatement process, a plant emitted large quantities of carbon dioxide or toxic (but non-radioactive) substances into the environment, resulting in environmental harm equal to or greater than that avoided by abating the radioactive discharges.

The production and treatment of effluents from a nuclear facility is typically subject to a requirement to use "Best Available Technique"[7] (BAT). This approach is compatible with the ALARA process inasmuch as their objective is to limit releases of radioactive effluents to the environment and doses to

[7] "Best Available Techniques (BAT) means the latest stage of development of processes, facilities or methods of operation which indicate the practical suitability of a particular measure for limiting waste arising and disposal" (definition from OSPAR Convention, 1992 – other definitions exist).

the public. But application of the optimization principle, to achieve exposures ALARA is focused more explicitly on ensuring doses to individuals from a source (e.g., a new nuclear power plant) are appropriately controlled, while application of the BAT principle is focused more explicitly at ensuring that effluent releases from that source are appropriately controlled. The two approaches are complementary and are sometimes merged together[8].

Implicit in the ALARA process and in the use of BAT is the idea that the optimum solution may change with time as new techniques (technologies and practices) are developed to a point where they may be deployed on an economically feasible scale. The point at which a technique becomes ALARA or BAT may depend on the installation in question. It is generally cheaper and more effective to incorporate a technique into a new installation than to 'back-fit' it into an existing one.

Other factors can be important as drivers for adopting new techniques. An example may be enhanced harmonization in terms of using a particular technological means of monitoring discharge rates. Another example is the role of socio-political drivers if, for example, national policies on what is economically or reasonably "available" change.

Note that ICRP originally assumed that if public (humans) are adequately protected from radiation and radioactive materials released, then non-human species and the environment would also be protected. The recent recommendations from ICRP (ICRP, 2014) indicates that it is necessary to apply optimization both to the protection of people and to the broader environment including non-human species (i.e. dose assessment for animals and plants). These recommendations might influence future assessments.

References

Aarhus, 1998. Convention on Access to Information, Public Participation in Decision-Making and Access to Justice in Environmental Matters, 1998.

EC, 1998. Radiation Protection following Iodine-131 Therapy, Radiation Protection Report 97, European Commission, Directorate General Environment, Nuclear Safety and Civil Protection, 1998.

EC, 2009. Technical Recommendations for Monitoring Individuals Occupationally Exposed to Ionizing Radiations, Radiation Protection Report 160, European Commission Directorate General for Energy and Transport, Nuclear Energy, 2009.

EC, 2010, European Commission guidelines on clinical audit for medical radiological practices (diagnostic radiology, nuclear medicine and radiotherapy).

EC, 2011, European Guidance on Estimating Population Doses from Medical X-Ray Procedures, Radiation Protection Report 154, Directorate General for Energy and Transport, Radiation Protection, 2011.

[8] More information about the two approaches can be find in Good Practice in Effluent Management for Nuclear Power Plant New Build - Report from the CRPPH Expert Group on BAT (EGBAT), CRPPH/R(2012)3, 2012.

EC, 2013. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom.

EC, 2014. Diagnostic Reference Levels in Thirty-Six European Countries, Radiation Protection Report 180, European Commission, Directorate General for Energy and Transport, Radiation Protection, 2014.

EC, 2009. Guidelines on Clinical Audit for Medical Radiological Practice, EU Guidelines n. 159, 2009.

EMAN, European Medical ALARA Network,
http://www.endlager-konrad.de/EN/bfs/we/international/eman.html

EPA, 2002. Principles for the Assessment of Prospective Public Doses arising from Authorized Discharges of Radioactive Waste to the Environment, EPA, 2002.

ESOREX, European Platform for Occupational Radiation Exposure website, https://esorex-platform.org

IAEA 2010, Clinical Training of Medical Physicists Specializing in Diagnostic Radiology, IAEA Training Course Series 47, IAEA.

IAEA 2007, Comprehensive Audits of Radiotherapy Practices: a Tool for Quality Improvement, IAEA.

ICRP, 2004. Release of Patients after Therapy with Unsealed Radionuclides. ICRP Publication 94. Ann. ICRP 34 (2).

ICRP, 2006. The Optimization of Radiological Protection - Broadening the Process. ICRP Publication 101b. Ann. ICRP 36 (3).

ICRP, 2010. Radiological Protection in Fluoroscopically Guided Procedures outside the Imaging Department. ICRP Publication 117, Ann. ICRP 40(6).

ICRP, 2013. Radiological protection in cardiology. ICRP Publication 120. Ann. ICRP 42(1).

ICRP, 2013a. Radiological protection in paediatric diagnostic and interventional radiology. ICRP Publication 121. Ann. ICRP 42(2).

ICRP, 2014. Protection of the Environment under Different Exposure Situations. ICRP Publication 124. Ann. ICRP 43(1).

ISOE, 2009. ISOE Work Management to Optimise Occupational Radiological Protection at Nuclear Power Plants, OECD 2009 NEA No. 6399.

RPOP, IAEA Radiation Protection Of Patient (RPOP)
https://rpop.iaea.org/RPoP/RPoP/Content/index.htm

3 ELEMENTS OF THE ALARA PROCESS IN EXISTING EXPOSURE SITUATIONS

Existing exposure situations concern everyone. Many of the cases do not generally require attention (e.g. ingestion of food with natural radioactivity) but some situations may require control and the application of the ALARA process. Optimization in practice for these cases is not always clear and the EAN 14th Workshop (Dublin, 2012) was focused on how the ALARA process can be applied for existing exposure situations. The elements presented below, come mainly from the summary and recommendations of the workshop (Shaw P, Croüail P, 2013).

3.1 Stakeholders

ICRP Publication 103 (ICRP, 2007) introduced the concept of "existing exposure situation" and defined it as "an exposure that already exists when a decision on control has to be taken, including prolonged exposure situation after emergencies" (§ 176). Such situations are very diverse but a specific feature appears to be that they involve a wide range of stakeholders; many of which are outside the traditional radiation protection community. For example, there is often a need for governmental involvement, with important roles for media and communication (e.g. in a radon national plan). The stress on individual behaviour to help people reduce their exposure ("self-help protection action") is also a feature in many cases (e.g. in radon remediation measures at home). Self-help protection actions cannot be imposed on people, so communication and stakeholder engagement at all levels appear especially relevant for such existing exposure situations.

3.2 Type of situations

Existing exposure situations vary significantly and may involve exposure from natural sources (e.g. radon indoor, cosmic radiation in aviation and in space flights, naturally occurring radioactive materials-NORM, NORM contaminated sites from past industrial activities, etc.) and man-made sources (e.g. living in contaminated territories after a nuclear accident or a radiation emergency). These situations also encompass a wide range of exposure levels: from µSv/year (cosmic radiation exposure of occasional aircraft passengers) to tens of mSv/y (contaminated sites after a nuclear accident and areas of very high natural background radiation). Generally, these situations are characterised by a broad individual dose distribution, often in the shape of a Gaussian distribution, whereas the dose distribution of a planned exposure situation is much more a skewed distribution, approaching a log-normal.

ICRP (ICRP, 2007) and the Euratom BSS (EC, 2013) recommend using "reference levels" as an optimization tool in existing exposure situations. A reference level is "*in an emergency exposure situation or in an existing exposure situation, the level of effective dose or equivalent dose or activity concentration above which it is judged inappropriate to allow exposures to occur as a result of that exposure situation, even though it is not a limit that may not be exceeded*" (EC, 2013) and for which protection actions should be planned and optimised. The factors to consider when choosing a reference level are the same as those required in the ALARA process (benefits/detriments and associated economic, societal etc. factors) and will depend on the prevailing circumstances of the exposure under consideration.

It should be noted that dose reference levels are often misinterpreted and used as a dose limit. It should also be noted that some existing exposure situations are managed as planned exposure situations, for example in workplaces where radon gas concentrations cannot be reduced below the reference level.

The potential for optimization is highly dependent on the exposure situation; thus, there is little scope for reducing doses from cosmic radiation exposure in aviation, and potentially huge scope for reducing radon exposures, both at home and in the workplace.

3.3 The use of reference levels in existing exposure situations

According to ICRP (ICRP, 2007) and the European EURATOM BSS (EC, 2013) "reference level" only applies in an emergency exposure situation or in an existing exposure situation and represents the level of effective dose or equivalent dose or other quantity (e.g. radon gas concentration) above which it is judged inappropriate to allow exposures to occur and for which protective action should be planned and optimised. Reference levels for public exposure for existing exposure situations should be set typically in the (1 to 20) mSv range of annual effective dose considering that "*a reference level below 1 mSv per year may be set, where appropriate, in an existing exposure situation for specific source-related exposures or pathways of exposure.*" (EC, 2013). Indeed, the EURATOM BSS states that the values chosen for reference levels shall depend upon the type of exposure situation and shall take into account both radiological protection requirements and societal criteria.

Optimization of protection should have priority in situations where individual exposures are above the reference level in order to first reduce exposures below this level. Optimization should then continue to be applied below the reference level. It is to be noted that the reference level can be changed during implementation of the optimization process in order to continually stimulate the general improvement of radiological protection (Lecomte, 2015). Moreover, it is worth stating that reference levels are *not* dose limits and they should not be treated this way.

3.4 Elements of ALARA process for existing exposure situations

An existing exposure situation already exists when a decision on the need for control is to be taken. When considering the need for control, the multiple exposure pathways, the range of doses received, the size of the population etc. should all be considered.
When the decision to control the exposure has been taken (justification), the distribution of exposures may often be large and there is a role for national, regional and even site-specific reference levels. The factors to consider when choosing the reference level are the same as those required for the ALARA process.

When establishing a protection strategy, the means by which optimization can be enforced should be considered. Regulation is a direct means of control but experience shows that it is not always applicable or may be of limited value. Therefore, optimization in existing exposure situations depends primarily on encouragement and assistance of a wide range of stakeholders. These stakeholders are generally not familiar with radiation protection issues. Therefore, elements of ALARA culture, such as attitudes and behaviour, education and training, engagement and participation of stakeholders, dissemination of information and lessons learned are considered necessary to raise awareness of self-help protection actions and to manage existing exposure situations.

Selecting protective actions in existing exposure situations can involve complex decision-making processes with the balance of risk, benefits, resources etc.; tools such as cost-benefit analyses can provide structure, clarity and rationality to support this process. Optimization is not minimisation: ALARA must have an end-point, as far as reasonable below the reference level. The situations are all different and the actual end-point will differ on a case-by-case basis.

The 14th ALARA Workshop dealt with this topic and its recommendation apply notably to:

- Radon exposure both in dwellings and public buildings – the comparison of the policies of the different countries (Ireland, Norway, France, …) is highlighted.
- Radiological exposure of aircraft crew against cosmic radiations,
- Naturally Occurring Radioactive Materials at workplace and at home,
- Management of contaminated areas (from past activities or long after a radiological accident)

Presentations are available at http://www.eu-alara.net/index.php/workshops-mainmenu-38/24-workshops/274-14th-ean-workshop-on-qalara-in-existing-exposure-situationsq.html

References

EC, 2013. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. OJ L 13, 17.1.2014. ICRP, 2007.

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Annals of the ICRP; 37 (2-4).

Lecomte JF, 2016. Understanding existing exposure situations. Ann ICRP; 45(1 Suppl):54-63.

Shaw P, Croüail P, 2013. ALARA in Existing Exposure Situations: 14th European ALARA Network Workshop, 4-6 September 2012, Dublin. J Radiol Prot; 33(2):487-90.

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4 ELEMENTS OF THE ALARA PROCESS IN EMERGENCY EXPOSURE SITUATIONS

According to ICRP definition (ICRP, 2007), an emergency situation arises from a planned exposure situation or malevolent act that needs urgent action to limit or reduce the unwanted consequences. In emergency exposure situations, justification and optimization of protection continue to apply for both public and worker exposures. However, due to the complexity and urgency, optimization should be integrated prior to the potential accident (planning stage) as well as during the implementation of an emergency response. As part of the preparedness, the intervention should identify phases and zones to facilitate the application of the protection measures commensurate with the circumstances: "urgent protective actions zone", "public protection zone" "precautionary action zone", etc. However, the classification of the zones, the size, the rationale for delimitation etc. are different across organizations and States (ENCO, 2012).

ICRP has set up a Task Group (TG 93) to update ICRP Publications 109 and 111 related to emergency situations in the light of the lessons from Fukushima and recent international developments concerning the protection of people in emergency exposure situations, and people living in long-term contaminated areas after a nuclear accident. The Publication, entitled 'Protection of People and the Environment in the Event of a Large Nuclear Accident', is expected in 2020.

4.1 Stakeholders

Emergency situations are an issue at national and international level. They involve:

- The utility of the installation facing the emergency;
- Specific national bodies set up in the case of nuclear (and/or chemical and/or biological) emergencies;
- Numerous national bodies and organizations such as military, health services, radiation protection laboratories, nuclear safety authority etc;
- Numerous local bodies and organizations: local police force, firemen, health service, civil protection;
- The public.

Generally, countries have established emergency response plans for different scenarios, assigning tasks and describing the role of the stakeholders. This is in line with current world-wide recommendations (IAEA, 2015) and regulation in Europe (EC, 2013). The involvement of stakeholders in 'peace time' is recognized as important to ensure that all the parameters related to emergencies have been addressed and optimized procedures are developed: trainings exercises and drills in conditions close to the reality are a key point. Assessment of radiation protection preparedness could be performed by self-assessment or by external inspection.

First responders are a specificity of emergency exposure situations. They are generally firemen from public services with specific skills in radiological interventions, workers from the plant, medical assistance etc. They are responsible for applying the procedures of the emergency plan. appropriately. Moreover, they should have an attitude towards limiting potential exposures not only for themselves but also for their colleagues and the public. Additionally, they should be able to identify possible problems and report them so that appropriate solutions can be identified and used with no loss of

time. Their feedback regarding the implementation of the plan is crucial for its improvement and must be considered during the normal reviews carried out by the planning team.

A second group of first responders may be comprised of a medical intervention team, evacuation team, drivers for evacuation etc. There is no exhaustive list in this case and this group may be constituted according to the circumstance. The difference with the former group comes from the fact that this group will not have to intervene on a nuclear installation. This group does not have particular radiation protection training or skill.

Radiation protection organizations at local, national and international levels are naturally fully involved in emergency situations (radiation protection department of the installation facing the emergency, radiation protection institute, nuclear safety authority, AIEA Incident & Emergency Centre etc.). These actors and their attribution are generally well defined in emergency plans.

It is recognized that the public should be at least aware of risks and radiation protection *before* the potential accident, although the practical implementation of this is not clearly addressed (EAN, 2018).

4.2 Types of situations

Definitions of zones, phases and timing of an accident response has not yet reached consensus internationally (ENCO, 2012) but globally the following phases can be identified:

- An acute phase when there is as yet no release of radioactivity outside the facility. The workers of the installation are potentially the only individuals under exposure, although protection actions may be initiated for the public. This situation is critical and marked by uncertainties about what will happen next and the extent of the accident. Given the uncertainties, it is sensible to incorporate a large safety margin in the decision-making.
- The intermediate phase comes after the releases. Decisions can be made based on on-site measurements and/or software evaluation of deposition and ambient dose rate. The protection measures should be linked with exposure pathways. The situation is characterized here by an approximate knowledge of the situation and its evolution, a potential high risk for the public and the need to take action quickly. Protective measures should be adjusted to the situation (available information, exposure vs. reference level etc.).
- The transition phase starts when the situation is stabilized (but the source is not necessarily secured). Decisions should be based on the analysis of the doses and the practical situation encountered on-site and off-site. Detailed knowledge of the exposure on daily life is possible and protective actions shall not be conservative but tuned and adapted to deal with external and internal exposures. More time for reflection and planning is available, the public should participate in the decisions to ensure their social acceptance.

In the late phase (e.g. some years after the accident), the emergency situation changes into an existing exposure situation. There is no clear-cut boundary that delimits the transition between emergency and existing situations. The decision on the transition will be taken by the competent authority based on the circumstances. The transition is not really a change in the radiological situation but a change on how it is managed.

As a result, the methods for optimization in emergency exposure situations evolve over the course of the different phases of the accident, from a focus on robustness, through to efficiency and speed and finally social acceptance.

Throughout the intervention, the models and arguments used must be simple and transparent, partly because those in charge of applying them are not usually the same people who developed them during the preparation phase, so they need to be able to assimilate them quickly and often in stressful situations; and partly to be able to communicate effectively with the public, as this communication and dialogue is key to the implemented protection measures gaining acceptance.

4.3 Reference levels

Dose limits do not apply for first responders engaged to save lives or prevent a catastrophic event in the case of emergency exposure situations. The ICRP TG93 recommends selecting a reference level in the 20 mSv to 100 mSv band, but a survey shows emergency reference level values/ranges are widely distributed: generally 100 mSv, sometimes 50 mSv or 250 mSv, even 500 mSv in Canada or Finland. Differences may come from the circumstances (life-saving actions vs. preventing deterministic effects actions).

Reference levels (RL) also apply for the public (ICRP, 2007) and, for the sake of operational monitoring, derived reference levels and intervention criteria can be calculated (IAEA, 2015) and used to decide whether or not to apply a protective measure or a set of protective measures.
The EAN Workshop n°17 on ALARA in Emergency Exposure Situations (EAN, 2017) was the opportunity to compare RLs. The key point is that there is a large variation in the interpretation, application and values given to RLs and derived RL, especially when it comes to:

- Their use in practice (benchmark vs. Action level, ceiling vs. Floor value etc.);
- The people exposed (*e.g.* Rl can be set for (emergency) workers, responders or the public);
- The affected environment or medium (foodstuff, ground contamination etc.);
- The unit of measurement (*e.g.* Rl for the whole body (msv) or a single organ (mgy); derived rl expressed in µsv/h, bq/kg etc.);
- The time frame (*e.g.* Rl set for one event, for a month, for a year etc.);
- Their use in determining the applicability of emergency mitigation measures such as sheltering, iodine intake, evacuation, relocation, resettlement etc.

This presents potential difficulties in applying RLs in the accident phase, particularly in terms of communication and perception by non-radiation specialists. Practical experiences from Japan and Belarus showed that RLs are regarded as a demarcation between safe and dangerous. This is reinforced by the fact that RLs are often put into regulation. Considering that RLs are expected to be revised, flexible and adaptable to the changing situation, this adds another layer of complexity to the situation.

In addition, derived reference levels might lead to over-conservatism due to inherently large uncertainties in dose assessments. The example of an RL derived from an annual effective dose and expressed in ambient dose equivalent rate (µSv/h) in Japan was particularly relevant (see 9.2).

4.4 Elements of the ALARA process in emergency exposure situations

As these issues need to be evaluated on a case-by-case basis, the optimization process is not detailed further.

Context

Protective measures for the public following a nuclear or radiological accident aim to avoid deterministic and to limit stochastic health effects to an acceptable level. First of all, this is a justification issue: below what dose are protective actions causing more harm than good? And respectively, above what doses are actions necessary to reach acceptable exposure levels for the population?

Problem at stake

During the "intermediate phase", the decision-making process is maybe the most complex one, not only balancing the cost of a protective action for direct (e.g. evacuation) or indirect (e.g. measures in the food chain) versus avoidable dose. It has to take into account acceptability of the action (or not to act); feasibility of the action; uncertainties (of projected releases, weather conditions etc., affecting the projected doses); the balance of health issues for the public and the effects on the emergency workers; waste problems etc. Time is also a constraint. In addition, the management of radioactive wastes in various forms (liquid, solid) will be another constraint in the short term.

When a protective action is considered justified, the decision maker has to make sure the magnitude and duration of the protective measures are optimised.

Methodology / protection action used

The justification is accorded by fixing generic intervention levels (often in terms of avertable dose) above which an action is almost always justified.

Generic protection actions (urgent phase) are:

- Iodine thyroid blocking;
- Sheltering;
- Relocation;
- Evacuation;
- Decontamination of individuals and medical intervention;
- Food, water and commodities restriction at domestic level and for international trade;
- Agricultural preventative measures (Euranos, 2009)

For first responders, in addition:

- Personal protective equipment (respiratory device, suits, decontamination facility etc.);
- Emergency dosimetry equipment (internal and external);
- Specific radiation measurement probes, airborne contamination probe etc.;
- The use of remote or unmanned robotics and drones.

As an example, evacuation intervention levels are generally higher than sheltering intervention levels because evacuation is more disruptive for the population, more costly, harder to implement, introduces particular problems (special groups such as children in schools, elderly in homes, inmates in prison, people in hospitals, animals left on their own, security issues etc.).

However, as indicated earlier, intervention levels differ greatly between organizations (who recommend them) and countries (who implement them) (EAN, 2017). In addition, these are generally only applicable for the urgent phase and are not considered for the other phases: so there is a gap in the strategy arrangements for longer-term protective measures and for the return to normality following an emergency. In reality, the impact of protective actions decided in an emergency on the longer term has not yet been addressed (ENCO, 2012). These issues were problematic in the Soviet Union after the Chernobyl accident and similar problems are still encountered in Japan after the Fukushima accident.

Decision making process / Results

In a real case with a release that might lead to dose projections larger than the intervention level for some part of the population, the size of the area to be evacuated and the duration of the evacuation has to be optimised to reduce the adverse effects of the evacuation. The use of dedicated computer codes to evaluate the direction of the releases, the position of the fall out etc. is advocated and numerous models and computer codes have been designed to help in the decision making process.

The problem of the size of the area to be evacuated has in many countries been resolved by defining evacuation areas as sectors around the predominant wind direction up to a certain distance. The width of the sector includes the uncertainties related to weather; the distance should be sufficiently conservative to cope with the urgent decisions to be made given a major release or threat. In real circumstances, the evacuation distance can be adapted to take into account the real threat.

Experience feedback from the Fukushima accident showed that mitigation measures can be questioned. This is especially where radiological data are not available and/or questioned and evacuation decisions are made on a distance-from-the-installation basis and not based on impact calculations or measurement. Some areas with large depositions were not evacuated in a timely manner, and people were sometimes evacuated to places with a larger deposition than where they had been (Diet of Japan, 2012).

Considerations of societal and ethical factors such as the social impact of protective measures (e.g. evacuation), economic costs both direct and indirect, environmental impact (e.g. wastes and how to manage them), are also of great importance – especially in the later phase when radiation protection will become less important. Trust in the decision process and the decision makers, and acceptance of the supporting measures are paramount in implementing the protective measures effectively.

Communication policy

Considering the large number of stakeholders and their diverse backgrounds, a large variation in the initial information, education, training and risk perception regarding the effects of ionising radiation and radiation protection is to be expected.

Reported experiences of exercises, rehearsals, and associated training proved to be beneficial for the preparation of emergency and first-responder workers.

Information given to the public by the authorities should be clear, precise understandable, unambiguous and credible. If not, there is a strong risk that the public will lose confidence and trust in the authorities and once lost it is difficult to rebuild, as was the case with both the Chernobyl and Fukushima accidents.

- Planning: Heightening public awareness (e.g. iodine intake, evacuation route) and RP radiation protection culture 'in peace-time' is recognised as necessary to put the radiation risk in perspective and establish a common understanding;
- Urgent/intermediate phases: Communication to the public should be clear, concise, with careful coordination between the authorities, utility, scientific organizations etc. to avoid overlap and confusion. Key messages can be made in advance and using multiple media platforms (lectures, meeting, radio, television, social media etc.).

In the longer term, people in affected territories should not be lectured about the situation but, instead, should be provided with awareness and support. Forums for discussing and sharing information with input from radiation protection experts should be set up. Tools should be provided to help individuals understand the nature of the radiological situation and support given to aid the development of "daily-life radiation protection culture".

References

Diet of Japan, 2012, The National Diet of Japan, Fukushima Nuclear Accident, Independent Investigation Commission. Chapter 4, Overview of the damage and how it spread.

EAN, 2017. Presentations made at the EAN 17th Workshop on ALARA in Emergency Exposure Situations, 15-17th May 2017, Lisbon, Portugal, https://www.eu-alara.net/index.php/activities/workshops/313-17th-european-alara-network-workshop-on-qalara-in-emergency-exposure-situationsq.html

EAN, 2018. Conclusions and recommendations from the 17th EAN Workshop 'ALARA in Emergency Exposure Situations', Journal of Radiological Protection 38 (2018), pp. 434-439.

EC, 2013. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. OJ L 13, 17.1.2014. ICRP, 2007.

ENCO, 2012. Review of Current Off-Site Nuclear Emergency Preparedness and Response Arrangements in EU Member States and Neighbouring Countries, ENER/D1/2012-474, ENCO FR-(13)-29, 2012.

EURANOS, 2009. Generic Handbook for Assisting in the Management of Contaminated Food Production Systems in Europe Following a Radiological Emergency, EURANOS(CAT1)-TN(09)-01, version 2, July 2009.

IAEA, 2015. IAEA Safety Standards, General Safety Requirements GSR Part 7, Preparedness and Response for a Nuclear or Radiological Emergency, IAEA, 2015.

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Annals of the ICRP; 37 (2-4).

5 ALARA IN PRACTICE FOR PLANNED EXPOSURE SITUATIONS

5.1 Occupational exposure in the nuclear, industrial and research fields

5.1.1 ALARA at the design stage of a nuclear power plant

Context

Application of the ALARA process at the design stage is a powerful way to identify potential exposures and implement protective actions in the design.

This example is based on the experience feedback of the French utility EDF in the design of the European Pressurized Water Reactor (EPR) of Flamanville 3.

Methodology

The steps of the adopted methodology were the following:

1. Identify a "reference collective dose" based on the feedback and best practices at current nuclear power reactors
2. Identify the key design evolution having an impact on radiation protection (source term, dose rates, exposed time) and estimation of the "Initial dose assessment"
3. Identify the key high=dose activities (i.e. those contributing to 50% of the collective dose) and implement optimization of radiation protection of these key activities
4. Estimation of the EPR optimised collective dose

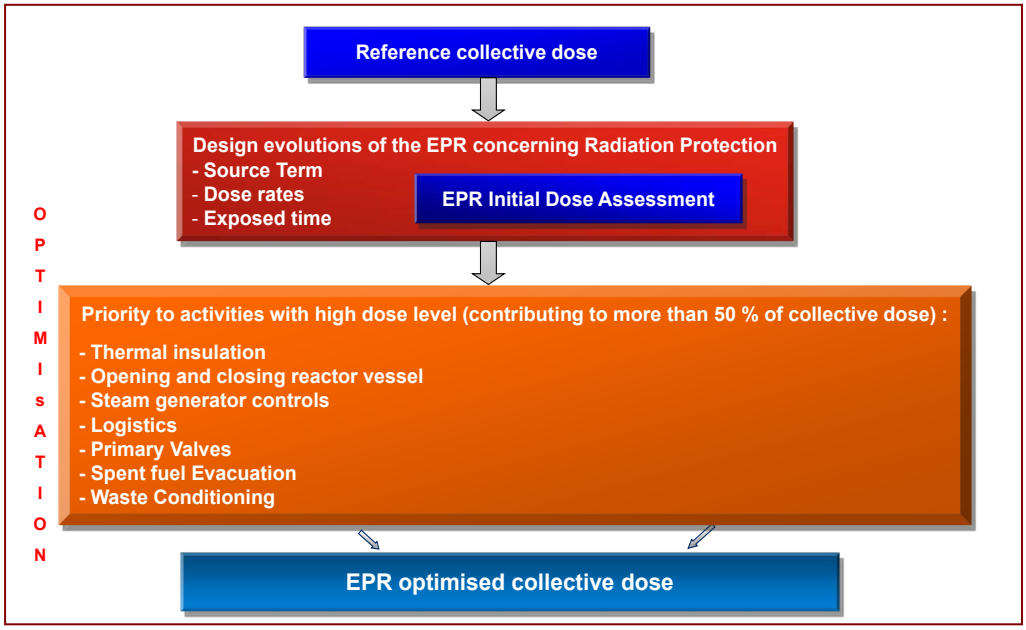

Figure 6. Methodology for establishing EPR collective dose

Main results

The results were as follows:

1. Identify a "reference collective dose" based on the feedback and best practices at current nuclear power reactors.

Based on the operational feed-back of the best plant in terms of collective and individual doses, averaged over 10 years (including 18 month cycle, 3 normal refuelling outages (i.e. with maintenance), 2 refuelling only outages (no specific maintenance) and one 10-year outage (with major maintenance)), the estimated reference collective dose is 0.44 man.Sv/year/reactor.

2. Identify the key design evolution having an impact on radiation protection (source term, dose rates, exposed time) and estimation of the "Initial dose assessment".

The EPR initial design presents an improvement that will have an impact on the source term of the reactor (significant reduction of stellites™ around valves and reactor pressure vessel internals as well as optimised chemistry of the primary circuit). The estimated result is a reduction of 15% in the dose rates. Furthermore, other design arrangements have made the reduction of dose rates possible in the workplace (e.g. specific walls separating the rooms), or the reduction of the exposure time to be spent in the plant for maintenance reasons (e.g. size of steam generator channel head).

The resulting initial dose assessment was 0.36 man.Sv/year/reactor.

3. Identify the key high-dose activities (i.e. those contributing to 50% of the collective dose) and implement optimization of radiation protection of these key activities.

The key activities and main improvements are the following:

- Thermal insulation removal and reinstallation (high individual doses): identification of the working places (pipes), planning of operation when pipes are in water, improvement of insulation systems making them easier to remove and reinstall
- Site logistics (high individual doses): design of fast mounting/dismounting scaffolds, installation of fixed platforms around main components
- Valves connected to the primary circuit: limitation of Stellite™ amount, improvement of valve sealing: double leak sealing barrier
- Reactor pressure vessel opening/closing (high collective dose): core internals handling under water, dedicated area for the vessel header storage
- Fuel evacuation (high collective dose): help with the fuel trolley positioning
- SG preparation and tests (high dose-rate activities): fast mounting nozzle dams, increase of the primary/secondary manhole diameters
- Waste conditioning (radiological cleanliness): waste treatment near their production location, possibility to check the waste conformity in the Nuclear Auxiliary Building

4. Estimation of the EPR optimised collective dose

The resulting optimised dose assessment is 0.35 man.Sv/year/reactor.

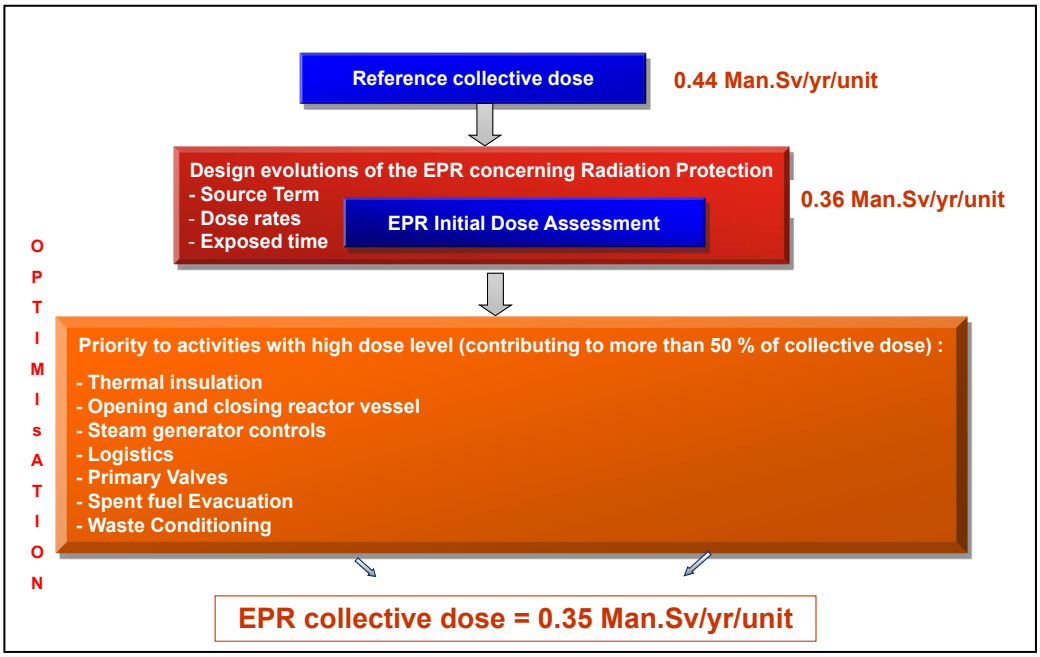

Figure 7. EPR collective dose calculations.

References

Radiation Protection in the design of the Flamanville 3 EPR, Noëlle EGLIZAUD, Stéphane MOREAU, Yannick BENETEAU, ISOE International Symposium, Cambridge 2010 (www.isoe-network.net)

Occupational radiation protection principles and criteria for designing new nuclear power plants, OECD 2010 NEA No. 6407

5.1.2 ALARA at the design stage of CENTRACO

Context

The CENTRACO is a nuclear centre for processing and conditioning very low and low-level radioactive waste in France. It processes scrap metal in its smelting plant and combustible waste in its incineration plant. The objective is to reduce waste volume, recycle whenever possible, and condition the remainder as final waste packages that can be accepted by ANDRA (the French national agency for radioactive waste management).

Issue

In 1997, at the design stage of CENTRACO, a first estimate of collective and individual doses based on a conservative hypothesis showed that in some areas, the predicted individual doses could be higher than 20 mSv/year (new dose limit to be implemented in France by 2000 according to the EC Directive 96/29). In addition, in some parts of the smelting plant, workers would have to wear individual respiratory protective equipment systematically and for prolonged periods.

In 1997, it was decided to review the design with the following objectives:

- Eliminate all situations where a worker could be exposed to more than 15 mSv/year (individual external dose constraint).
- Eliminate all situations where a worker should have to wear individual respiratory protective equipment systematically and for more than 2 hours (internal dose constraint).
- Review all workplaces to optimise the radiation protection and reduce exposures ALARA below the individual dose constraint.

Methodology

The following steps were adopted:

- New evaluation of the dose predictions on the basis of a much more realistic hypothesis, with a more exhaustive description of the workplace organisation, the tasks and jobs to be performed as well as an estimation of the individual dose distribution.
- Identification of critical workplaces: i) a first group of workplaces where the individual dose could be higher than 15 mSv and/or an individual respiratory protection had to be worn; ii) a second group of workplaces where individual dose could be lower than 15 mSv/year.
- Identification and selection of protection options: for the first group of workplaces, identification of the most efficient design modifications to secure compliance with the external and internal dose constraints. For the second group, implementation of an ALARA procedure to identify and select protective actions using a cost-benefit method (use of a monetary value of the unit of collective dose).

Main results

The selected protective actions resulted in a major modification of the design of the smelting plant, as well as other types of actions (e.g. use of robotics, adaptation of workplaces, strengthening of shielding).

The following tables (Table 1 and 2) present the dose estimates before and after the implementation of the optimization process:

Table 1. Collective and mean individual dose

	Collective Dose - Operation (man.Sv/year)	Collective dose - Maintenance (man.Sv/year)	Total collective dose (man.Sv/year)	Number of exposed workers (operation and maintenance)	Mean individual dose for operation (mSv/year)	Mean individual dose for operation and maintenance (mSv/year)
Initial situation (realistic)	0.77	0.110	0.88	125	8.8	7.0
After optimization process	0.53	0.11	0.64	130	5.7	5

Table 2. Individual dose distribution

		Number of individuals			
		< 5 mSv/year	5 - 10 mSv/year	10 - 15 mSv/year	>15 mSv/year
Smelting Plant	Initial situation (realistic estimates)	13	11	6	3
	After optimization process	33	3	2	0
Incinerating plant	Initial situation (realistic estimates)	8	13	14	10
	After optimization process	8	36	1	0

Lessons learned

The optimization procedure can be applied effectively at the design stage of facilities. It should be implemented as soon as possible in the design process, when it is still possible to modify the main structures or process. The use of an external individual dose constraint in this specific case resulted in a change of the predicted individual dose distribution, with a shift to the lower levels of exposure. The use of an "internal dose constraint" has helped to modify the workplaces in such a way as to facilitate the working conditions of the workers with less working hours wearing individual respiratory protection.

Reference

Centraco - une optimisation de la radioprotection à la conception, Jean-Philippe ANDRE, Claude ROELS, Jean-Pierre DEGRANGE, Journées SFRP sur l'optimisation de la radioprotection des travailleurs dans les domaines électronucléaire, industriel et médical - La Rochelle, 9-10 Juin 1998

5.1.3 ALARA organization in a nuclear power plant

At Cernavoda NPP (Romania), dissemination of the ALARA culture is based on the following organisation:

The work groups' ALARA Coordinators:

- Analyse the monthly dose reports for their work groups (doses received against dose targets, doses received for major works / activities);
- Are involved in the issuing and follow-up of the work group ALARA objectives and indicators, and the dose reduction plans.

The ALARA Technical Committee is responsible for:

- Pre/post-job ALARA evaluation for activities and jobs with > 20 man.mSv estimated collective dose;
- Analysis of those activities established through the self-assessment process;
- Establishing ALARA specific objectives and targets;
- Analysis of the evolution of dose-related performance indicators;
- Collection, analysis and evaluation of data to determine the efficiency of the ALARA Process; ALARA cost – benefit analysis;
- Evaluation and approval of the action plans to decrease the exposure at the work groups level.

The ALARA Committee approves ALARA objectives and targets and performs trend analysis of ALARA performance indicators and, if necessary, establishes corrective actions and modifies the objectives. The ALARA objectives include reducing:

- Plant and work group collective doses (man.mSv/year);
- Planned outages collective dose (man.mSv);
- Major works collective dose (man.mSv);
- Plant internal collective dose (% from plant collective dose);
- Work group internal collective dose (% from work group collective dose).

Reference

Work Management to optimise occupational radiation protection in the nuclear power industry, © OECD 2009 NEA No. 6399.

5.1.4 Specifics of the ALARA approach for activities during the decommissioning of nuclear installations

Context

Decommissioning activities are rather different from operational activities when it comes to the source of radiation and its evolution with time, the activities to be performed and their duration.

Methodology

Specific features of decommissioning have impacts on important steps of the ALARA approach:

1. Careful critical analysis of the initial data (radiological conditions, workload) must be performed to be able to track changes in these conditions. In parallel, a sensitivity analysis must be performed on the selected optimization actions.
2. Regular hold points should be incorporated to take stock and monitor changes in the initial conditions, and to check the agreement between the projected and actual doses.
3. Efforts should be made to collect feedback experience for future decommissioning activities. Even if each activity or installation is unique, there is an interest in identifying general good practices or ways to improve.

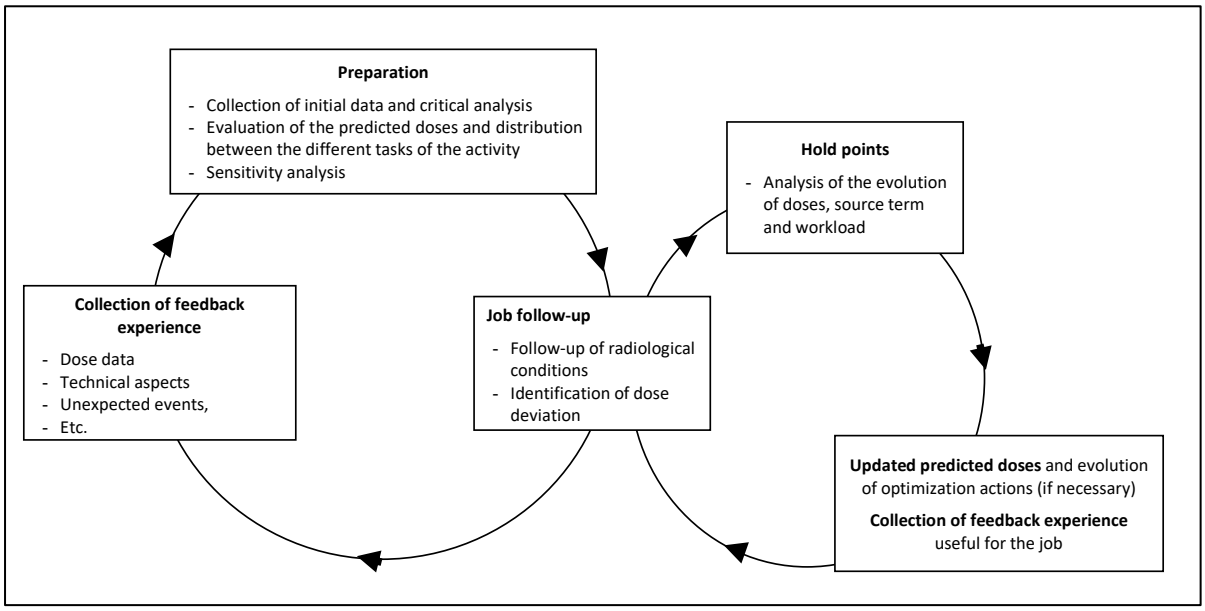

Figure 8. A proposed approach for ALARA at the decommissioning stage of nuclear installations

Main results

The table below list some of the 'ALARA-answers' to the specifics of the decommissioning activities.

Table 3. Some specifics of the decommissioning work and related ALARA answers.

Specifics of dismantling activities	Issue raised	Answer and revision of the ALARA approach
- Uncertainties on the source term - Loss of knowledge of the installation and on the events which occurred in operation	- Difficulties in the evaluation of initial radiological conditions - Differences between projected and actual radiological conditions	- Dose rate measurements/mapping adapted to the task to be performed - Modelling of radiological conditions using hypotheses as realistic as possible - Confirm the expected radiological conditions just before starting the work
- Duration of the activities - Repetitive tasks	- Difficulties in the assessment of the exposed workload - In the case of repetitive tasks, make allowance for progressive improvements in working methods	- Regular hold points during the realization of the activities - Regular analysis of the evolution of the dose assessment
- Evolution of the source term during activities	- Anticipation of the source term evolution during the preparation of the activities	- Sensitivity analysis during preparation - Regular hold points during the realization to update the dose assessments if necessary
- New activities - Unique installations	- Lack of feedback experience - Use of existing feedback experience from different design installations	- Need for collection of feedback experience both during and after the activities - Collection of feedback on general techniques and issues raised by the techniques
- Long workload in very low dose rate areas	- High "theoretical" dose, which might not be registered because of operational dosimeter registration limits - Overestimation of the doses associated with these activities	- Favour electronic dosimeters with low registration limits - Follow up of the evolution of dose with regular hold points

Reference

Specificities of the ALARA approach for activities during the decommissioning of NPPs, François Drouet, ISOE International Symposium - Cambridge - November 2010
(proceedings available on www.isoe-network.net)

5.1.5 Tools for education and training

Context

The National Institute for Nuclear Science and Technology (INSTN Teaching Unit of Cherbourg-Octeville) and OREKA (a company specialized in 3D-engineering) have developed a prototype of an innovative teaching tool named O.S.I.R.I.S. (Tool for Simulation of work under ionising radiation).

Methodology and results

The OSIRIS tool provides a 3D virtual training environment that allows trainees to practice different aspects of nuclear safety for work-stations where workers are exposed to radiation, using a series of "games". Typical users would be students or professionals (for example Competent Persons in Radiation Protection in France) who need to learn how to protect workers against radiation.

In this game, the action is located in the steam generator building of a pressurised water reactor during a check on the piping system. Users can move freely within this virtual environment, which they view through a camera positioned at eye level.

By using the navigating device, trainees are able to move from scene to scene in real time during different phases of the operation. They can use a range of instruments such as radiation survey meters, or probes to measure loose contamination on smears.

The objectives of the game are:

- To determine the individual and collective doses received by workers during all phases of the checking operation ("predictive dose evaluation").
- To implement the three principles of radiation protection (principle of justification, principle of optimization - ALARA principle - and principle of limitation). In particular, trainees learn to think about the different ways of reducing the dose received (exposure time, shield, distance, and activity), and how to achieve an optimized assessment of dose.
- To supervise the collective dose accrued (daily), and to know how to react in case of emergency (for example alarm on the dosimeters), or if the collective dose increases.
- To analyse the dose recorded during the operation (i.e. the discrepancy between the predictive collective dose and the collective dose achieved).
- To determine how to improve a) the accuracy of predictions and b) the identification of, and response to, emergency situations.

Figure 9. Example of view from OSIRIS in the steam generator bunker

- Window ① on the image allows the user to know the duration of stay in the environment and also the effective dose received by the user in mSv.

- Window ② tells the user the dose rate measured in real time by the dose rate meter (in mSv/h). On the left there is a list of commands available to the user. On the right, the user can choose between different survey instruments (dose rate meter, telescopic probe, smears).

- Window ③ is a map telling the user where he is in the building.

Reference

A Serious 3D Game for Education and Training in Radiation Protection, Pin, A.; Massiot, P. - Transactions of ETRAP 2013 Conference, Vienna (Austria), 12-15 March 2013 pp. 241-249
http://www.euronuclear.org/events/etrap/etrap2013/transactions.htm

5.1.6 ALARA in the dismantling and decommissioning of the BR3 reactor - a mixed risk case: radiation and asbestos.

Context

The BR3 reactor was the first PWR (pressurised water reactor) in Western Europe and also the first one being decommissioned. Within the framework of the European five-year programme for research and technological development for the decommissioning of nuclear installations, BR3 was chosen, next to three other European installations, as a pilot project for the demonstration of the decommissioning of PWR plants. A second objective of this programme was to address the issue of the implementation of the ALARA principle in decommissioning operations.

Problem

As required by the Belgian regulations, the safety of the workplace has to be guaranteed, including air quality. In this case, thermal insulation was present containing asbestos. This compound is a proven initiator of lung cancer, and strict air concentration limits have been set by law. During the BR3 decommissioning project, measurements indicated that this limit was reached in some workplaces located in controlled areas. Actions were undertaken in order to remove the asbestos. The removal of asbestos has to be performed under stringent conditions fixed in Belgian legislation; only accredited companies are allowed to undertake such removal operations. The main challenge was to optimize the process, bearing in mind both requirements: radiation protection and safe removal of asbestos.

Methodology

The Health Physics department, in close co-operation with the BR3 management, decided:

- to invite the external company for a visit to the workplace and to inform them of the radiation protection measures to be followed by all workers in controlled areas;
- to require a detailed procedure describing the removal operations as well as the protective measures against the risk of asbestos inhalation;
- to develop, in addition to the daily monitoring of the workers, special monitoring of internal contamination of the external workforce; this was done for psychological reasons but also to detect, a potential internal contamination from asbestos;
- to inform all Belgian regulatory authorities concerned with radiological and non-radiological protection of workers – about this methodology.

Main results

Due to this ALARA approach involving both the external workers and the BR3 workers, it has been possible:

- to reduce the number of required working days from 50 to 35;
- to reduce the number of external workers required for the removal operations;
- to avoid any air contamination with asbestos;
- to remove twice as much insulation material as planned.

As a consequence, the total collective dose for the whole operation was a factor 4.5 lower than the expected dose (19.2 man.mSv instead of 88.9 man.mSv).

Lessons learned

Many valuable lessons have been collected during this removal project: examples are:

- Optimization does not prevent compliance with other requirements concerning other industrial risks; on the contrary, an ALARA approach contributes to a higher level of awareness and individual commitment to safety;
- An open-minded approach with respect to all regulatory requirements and with adequate interactions with all authorities allows time-, dose- and cost savings;
- In such projects, time has to be made available to inform the external workforce initially and different styles of behaviour have to be kept in mind;
- Detailed procedures need to be discussed between all the involved stakeholders and operators;
- Flexibility has to be allowed in order to cope with the technical, human and regulatory requirements.

Reference

20 Years of ALARA Management, Research and Development at the Belgian Nuclear Research Centre SCK•CEN, Frank Hardeman, Pascal Deboodt, Philippe Antoine and Fernand Vermeersch, IRPA Glasgow 2012

5.1.7 A decontamination procedure for an experimental loop in the BR2 materials testing reactor

Context

The BR2 reactor is a material testing reactor used for the production of medical radioactive isotopes, for the doping of high quality Si, and for testing the behaviour of reactor materials and fuels. One of the major experimental loops within the BR2 reactor is the so-called Callisto loop. This loop simulates PWR temperature, pressure and water conditions, and allows the irradiation of materials for use in reactors in very high neutron fluxes for characterization and for prediction of their behaviour.

Problem

The Callisto loop was installed in the early '90s, and due to deposition of activated materials at various positions, the dose rate around the loop has been rising throughout its operation. This had a negative impact on the dose to the workforce performing the maintenance of major components of this loop. The maintenance and inspection activities in the so-called Sub Pile Room (underneath the BR2 reactor and containing the major components of the loop such as the primary pumps) lead to a collective dose of 18.34 man.mSv in 2008.

Methodology

As a topic within the periodic safety review of the BR2 facility, it was decided to investigate the possibility of decontaminating the loop. Decontamination has the advantage of reducing future exposures if further maintenance operations are performed. It has the disadvantage that the operation itself leads to exposure of the people performing it, the production of radiochemical wastes and possible damage to the loop if a sub-optimal chemical cocktail is used or if technical problems occur during the decontamination. After some test experiments, it was decided to proceed with the decontamination and this was performed in 2011. Actors were: in-house staff specialised in this domain, in co-operation with the BR2 staff and the Health Physics department.

Main results

- The decontamination of a major part of the Callisto loop lead to a collective dose of 5.5 man.mSv, with a maximal individual dose of around 0.8 mSv. (One part of the loop was not decontaminated because of some uncertainty of chemical compatibility between these components and the optimal cocktail to decontaminate the other parts);
- The operation took place without incident (neither radiological nor chemical);
- The real doses were very comparable to the dose estimations;
- Predictions made indicate that future in-service inspections will lead to doses 4 to5 times lower than in the past.

Lessons learned

Many valuable lessons have been collected during this project: examples are:

- Optimization includes an adequate balance between process control (sampling and subsequent radio-activity analysis), dose and effectiveness of the operations: very frequent sampling allows adequate adjustment of the technical parameters yet leads to higher doses (due to the more frequent interventions and sample manipulations).
- A good cooperation between specialists (in decontamination in this case), operators within the facilities and the Health Physics department leads to reliable dose predictions and to successful operation of complex processes avoiding incidents. Involvement of all stakeholders and operators is vital.

- Optimization includes the balance between a gain in dose reduction on the one hand, and the risk of future operational difficulties that might lead in turn to higher doses. That is why a part of the loop has not been decontaminated.

Remark: Major decontamination operations have also been adopted successfully during the BR3 decontamination process at the level of the primary circuit (Klein and Valenduc, 2002).

References

20 Years of ALARA Management, Research and Development at the Belgian Nuclear Research Centre SCK•CEN, Frank Hardeman, Pascal Deboodt, Philippe Antoine and Fernand Vermeersch, IRPA Glasgow 2012.

Decontamination strategy for the dismantling of strongly contaminated loops: the practical case of the dismantling of the BR3 PWR auxiliary and primary loops, Michel Klein and Pierre Valenduc, 3rd European Forum of "Radioprotectique" - Radioprotection and logic of dismantling, October 2 – 4, 2002 - La Grande Motte, France

5.1.8 ALARA in industrial radiography

Context

Gamma radiography is an important tool in non-destructive testing (NDT) on construction sites and remote locations. Main applications are weld inspection on oil and gas pipelines, power plants as well as in chemical and petrochemical production sites. Gamma radiography is a very economical and at the same time safe process to ensure operational safety of inspected assemblies resulting in better protection of human health and environment. Gamma radiography completes the full range of a modern NDT business, particularly where other methods are inapplicable, e.g. due to lack of electricity out in the field in pipeline building.

Problem

Despite – or maybe because of– its relative simplicity, the use of industrial radiography apparatus is often the cause of non-negligible radiological exposures (for example an average of 4 mSv/y in the French Institute of Welding in 2012) and regularly leads to accidents (for example non-retrieval of the source inside the shielding) that appears on the IAEA and RELIR/OTHEA websites.

Methodology

Considering this situation, the French Institute of Welding has designed an alternative solution called GammaProx (See Figure 10) for industrial radiography.

- The source is made of selenium-75 rather than iridium-192. Compared to iridium, selenium has a lower dose rate for the same activity, thus reducing the dose rate of the operator and the size of the controlled area.
- The use of a specially designed collimator also allows a reduction in scattered radiation. A smaller controlled area is easier to signal and manage.
- Furthermore, the use of depleted uranium shielding as needed for iridium is no longer necessary.

Figure 10. GammaProx (contact version) in control situation.

The use of the GammaProx is recognized to have an impact on the dose rate of the Institute of Welding workers as the average dose has dropped to 1.9 mSv in 2014.

As in every ALARA case, the proposed solution has drawbacks. In this case, selenium having lower energy and thus less penetrating emission cannot be used on thick material. Furthermore, selenium sources are made of powder (highly volatile) while iridium sources are solid metal, raising the question of consequences in the case of source destruction. Finally, a selenium source is more expensive and maybe not affordable for every company.

References

Presentations made at the occasion of the 16th ALARA Workshop:

Reducing the Size of Radiography Controlled Area, C. Bergeron from the Institute of Welding, France,

ALARA in Radiography, Michael Fuller on behalf of the International Source Suppliers and Producers Association (ISSPA)

For typical cases of incidents linked to industrial radiography, see also "Ionising Radiations Incident Database (IRID) and RELIR, link on EAN homepage: http://www.eu-alara.net

5.2 Occupational exposure in the medical field

5.2.1 Brachytherapy using Rhenium-PTA

Context

Rhenium-PTA is used for endovascular brachytherapy interventions to prevent renewed constriction of the arteries (restenosis) after peripheral angiography (PTA).

During the preceding angioplasty intervention, a PTA balloon catheter is introduced in the constricted part of the artery. After the successful placement of the catheter, the integrated balloon is filled with a Re-188-perrhenic solution with an activity concentration of about 5 GBq/ml. Through the thin texture of the balloon, the rhenium solution can irradiate the localised affected area to reduce adenoids of the cells and thereby inhibit constriction of the arteries.

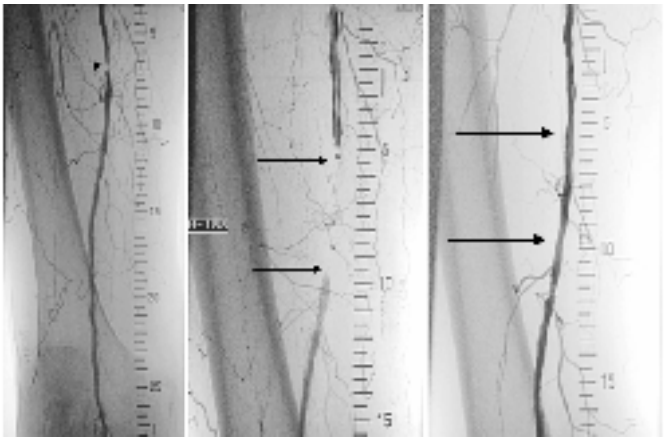

Figure 11. Arterial Balloon Dilatation

Issue

In a joint study made by the BfS and the Central Clinic of Augsburg, the finger dose of the personnel involved in the treatment has been measured regularly over 2 years. The information gathered was used to optimize the treatment and subsequently reduce the radiation exposure for the operator and the physicist.

Methodology

In order to determine the maximum skin dose, the exposure for an activity of 25 GBq was calculated on the assumption of typical treatment times and distances to the source. In a second step, the specific dose was measured with the help of the LB1310 radiation measuring device (Berthold) from a 30cm distance, the dose was extrapolated to small distances. To measure the maximum local skin dose ($H_P(0,07)$) thermo-luminescence dosimeters (TLD) receptive to beta and photon radiation (Type MCP-N), were attached with the help of perforated adhesive strips to the fingertips of the personnel.

Figure 12. TLD prepared operator hands

For the series of measurements, the use of long gripping tools, a lead container and a 10 mm acryl glass syringe shielding was compared to the newly developed Application Support Kit (including accessories).

The calculated estimation of the exposure of the original treatment (without improvements) indicated a maximal local skin dose of approx. 30 mSv per treatment on the physicist's and physician's hands. Based on these numbers, the overall annual skin dose would, on the assumption of 75 interventions per year, have greatly exceeded the annual limit of 500 mSv.

To optimize protection during the application processes, a special application device was developed as well as a waste box.

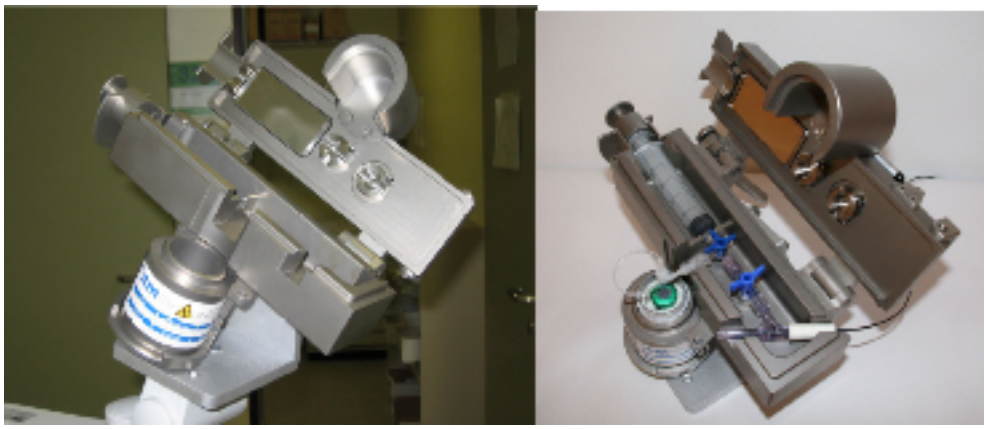

Figure 13. Application device

Main results

Through the optimized handling and the consequent use of long gripping tools, the maximal local skin dose could be reduced to <0.1 mSv during the preparation and to 3 mSv and 1 mSv during the application for the physicist and for the operator, respectively (see Figure 1). Through the use of the Application Support Kit and a redesign of the waste container, the radiation exposure of the personnel was significantly reduced by a factor of more than 10.

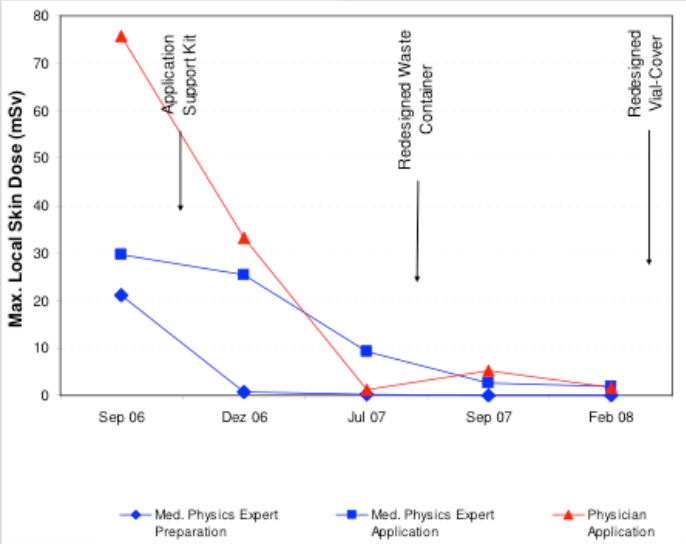

Figure 14. Results of Optimization

Physical Properties of Rhenium-188:

- Half-life: 17.0 hours
- Decay energy: Beta decay, E_{max} = 2.12 MeV
- Chemical form: $(^{188}Re)ReO_4^-$ in isotonic saline solution

This case study has been contributed by J.Kopp and H. Wengenmair, University Hospital Augsburg, and I. Barth, BfS.

References

Endovascular Brachytherapy with Rhenium-188, Jürgen Kopp, Hermann Wegenmair, Giesbert Leissner, Ilona Barth, Arndt Rimpler, 13th EAN Workshop on "Alara in the Medical Sector", Oscarborg, Norway, June 2011. (www.eu-alara.net)

ALARA in Handling of Beta-Emitters – Measurement Techniques and Optimisation, Ilona Barth, Arndt Rimpler EAN Newsletter Issue 29, October 2011. (www.eu-alara.net)

5.2.2 Staff exposure in interventional radiology

Issue

Radiologists performing interventional procedures are often required to stand close to the patient's side when carrying out manipulations under real-time x-ray imaging. This can result in their extremities receiving a high radiation dose, due to scattered radiation. These doses are sometimes high enough to warrant classification as radiation worker. The doses to the legs of radiologists have received less attention than those to the hands, however the doses may be high, due to the proximity of the legs and feet to scattered radiation. The routine monitoring of extremity doses in interventional radiology is difficult due to several factors.

Firstly, a wide range of interventional procedures is undertaken in every radiology department, and these procedures require many different techniques, equipment and skills. This means that the position the radiologist adopts in relation to scattering medium and therefore their exposure, depends heavily on the type of the procedure. As the hands which manipulate the catheters within the patient are often located close to the patient's side and to the area under irradiation, the distribution of dose across the hands can be variable, with very high localised doses, making routine monitoring difficult.

Methodology

The doses to the hands and lower limbs were measured using thermoluminescent dosimeters. A total of 16 Li F:Mg,Ti TLD100 chips were attached to both aspects of the hands. The TLDs were positioned longitudinally and transversely across the hand in order to obtain information about the distribution of dose across the hands. All TLDs were sealed in plastic and taped to the hands prior to radiologists scrubbing up, and then worn underneath the surgical glove. Four TLD100 chips were also attached to the theatre trousers of the radiologists per procedure. Radiologists were monitored in a total of 100 procedures in six hospitals in Scotland, ranging from large teaching hospitals to smaller district general hospitals. This provided data regarding a wide range of procedures, carried out on a wide range of equipment and performed by radiologists of differing experience.

Main results

The magnitude and distribution of doses that radiologists receive to their hands when undertaking interventional procedures can vary greatly. Of most importance is the type of procedure being performed.

Biliary procedures in general produced the greatest dose to the radiologist, the mean dose across the hands ranged from 0.38 to 5.37 mSv per procedure across all 7 hospitals studied. This was due to the need for the radiologist to place their hands very close to the area being irradiated, in order to manipulate the catheter effectively.

The TIPS procedures (Transjugular Intrahepatic Porto-systemic Shunt) provided a wide range of doses to the hands of radiologists, over the two centres studied. Although the hands were not located near the x-ray field the hands still had the potential to receive a significant dose. This was due to the duration of some procedures, the technical difficulty in completing the procedure and the differences in equipment used between the two centres.

The dose to the hands when performing stenting, angioplasties and angiograms ranged from 0.02 to 1.60 mSv per procedure. Stenting and angioplasties were at the higher end of the dose scale, while

angiograms contributed the smallest dose, as the majority of the procedure could be performed from behind a lead screen.

Radiologists performing embolization procedures were exposed to a mean hand dose of 0.04 to 0.40 mSv per procedure.

The results show that the legs of radiologists may receive a significant radiation dose, which in some cases may even be higher than that received by the hands. The magnitude of this dose was dependent mainly upon whether lead protection was used, the procedure and the complexity of that procedure.

The dose to the legs was generally lower than that to the hands (from 0.2 to 0.61 mSv/procedure to 0.5 to 2.61 mSv/procedure depending on the procedure). When lead protection is used the doses were in most cases significantly lower, in some cases the dose tended towards the detection limit of the TLDs used.

One exception was found in a hospital where a mobile lead screen is used, which is mounted on castors and can be located anywhere within the room. This poses a problem, as the screen must be put in place before the procedure starts. Consequently, the screen was not used in the majority of embolization procedures, and therefore the leg doses are significantly higher than those to the hands.

Lessons-learned – what about routine measurements?

The routine monitoring of interventional radiologists is clearly difficult. A radiologist whose workload consists of a wide range of both diagnostic and therapeutic procedures would be best served using a TLD ring located at the base of the little finger. In the majority of procedures this is the area of highest dose, and therefore would provide a good indicator of their dose over a period of time. The routine monitoring of leg doses is problematic. A rule of thumb was established which could be used to establish whether a lead screen should be purchased. A dose-area-product meter (DAP) reading of 100 Gy cm^2 will give a dose of approximately 1 mSv to the most exposed leg. If lead protection is used, the dose would drop to 0.02 mSv.

Reference

Extremity Doses to Interventional Radiologists, M. Whithy, C.J. Martin (Health Physics, Department of Clinical Physics and Bio Engineering of the Western Infirmary, Glasgow, Scotland) presented at the occasion of EAN 6th Workshop on Occupational Exposure Optimization in the medical field.

5.2.3 A nuclear medicine and PET facility shielding design tool

Issue

The goal of nuclear medicine and positron emission tomography (PET) facility shielding design is to keep doses to workers and the public as low as reasonably achievable (ALARA).

Methodology

A software tool written in Interactive Data Language (IDL) 6.0, ALARA-CAD, reads bitmap-format floor plan images on which the user can locate and describe radioactive sources (e.g., radionuclide, activity, times, studies/year); shielding structures (e.g., material, dimensions); local occupancy factors; and other facility features, such as floor-to-ceiling height. Doses to all points on the floor plan and to the floors above and below are calculated and include consideration of broad beam attenuation and radionuclide energy and decay.

Dose maps are displayed in grey scale or colour to facilitate hotspot detection.
Sources can be moved, protocols and occupancies adjusted, shielding structures added/modified and doses recalculated and redisplayed until ALARA values are achieved. Figures, parameters and results tables can be saved for report generation.

Expected result

The use of the ALARA-CAD software is expected to contribute to the proper shielding design for nuclear medicine and PET facilities through:

a. The calculation of doses to occupants of the facility and adjacent regions based on projected layouts, protocols and workflows, and
b. Reduction of doses to ALARA through adjustment of the aforementioned parameters and introduction of attenuating media.

Reference

ALARA-CAD - A Nuclear Medicine and PET facility shielding design tool, Maggie Kusano and Curtis Caldwell in The Journal of Nuclear Medicine. 2008; 49 (Supplement):155p.

5.3 Patient exposures

5.3.1 Patient doses in CT examinations in Switzerland: implementation of national diagnostic reference levels

Issue

Diagnostic reference levels (DRLs) were established for 21 indication-based computed tomography (CT) examinations for adults in Switzerland.

Methodology

One hundred and seventy-nine of 225 CT scanners operated in hospitals and private radiology institutes were audited on-site and patient doses were collected. For each CT scanner, a correction factor was calculated expressing the deviation of the measured weighted computed tomography dose index (CTDI) to the nominal weighted CTDI as displayed on the workstation. Patient doses were corrected by this factor providing a realistic basis for establishing national DRLs.

Main results

Results showed that most of these DRLs are similar or slightly smaller than previous DRLs, which were partly derived from a national survey in 2004 and recommendations of the European Commission. However, for examinations of the petrous bone, pelvis and lower limbs, DRLs were increased by a factor ranging between 1.5 and 2.

Lessons learned

The observed broad dose distributions indicate that the concept of DRLs has not yet been fully understood and implemented in routine clinical practice. Further efforts are required to reduce patient doses. These include (1) periodical re-audits, (2) the establishment of a consulting service free of charge that provides expert advice to radiologists on CT protocol optimization and (3) the introduction of clinical audits to identify and eliminate unjustified CT examinations.

Reference

Patient doses in CT examinations in Switzerland: implementation of national diagnostic reference levels, R. Treier, A. Aroua, F. R. Verdun, E. Samara, A. Stuessi and Ph. R. Trueb in Radiation Protection Dosimetry (2010), Vol. 142, No. 2–4, pp. 244–254 doi:10.1093/rpd/ncq279 Advance Access publication 6 October 2010.

5.3.2 Example of patient dose optimization in interventional radiology

Issue

In October 2009, the Academic Hospital of Clermont-Ferrand (general hospital of about 2000 beds) declared to the French Authority the overexposure of a patient after a radiological procedure. This event concerned a 30 year-old patient, after two uterine artery embolizations justified by life-threatening recurring post-partum bleeding. The skin dose has been estimated to be between 12 and 16 Gy by the Institute for Radiation protection and Nuclear Safety (IRSN).

This unwanted event took place within the Department of Vascular Radiology, whose activity is both diagnostic and interventional. It has been the starting point of a global optimization process, initiated by the Department, with the technical support of IRSN.

Methodology

Certain optimization actions were successively undertaken in 2010 on one of the two hospital's radiological units dedicated to vascular and visceral interventional procedures (Allura®PHILIPS).
Initially, for the most frequent procedures, the technical parameters were analysed and DAP values were collected for about 20 patients. Three steps of optimization have been successively proposed by IRSN, and implemented after medical validation based on image quality:

- Reduction of the "routine" frame frequency (6f/s to 3f/s in "Graphy mode") resulted in a dose reduction of a factor of 2.
- Manufacturer up-grade of the generator: higher kV and additional filtration resulted in:
    - dose contribution of the "Graphy mode" reduced by about 45%,
    - dose contribution of the "Fluoro mode" reduced by about 15%.
- Implementation of a new "low-dose" fluoro mode in routine practice, after evaluation of the quality image and of the associated dose saving. This action resulted in a dose contribution of the "Fluoro mode" reduced by about 20%.

Lessons learned

Technical recommendations provided by IRSN allowed the department to optimize significantly their interventional equipment. However, the key of the success of this initiative was the involvement of all the actors: practitioners, medical staff, radiographers, biomedical engineers of the hospital and manufacturer. Care must now be taken to maintain, or even to improve, these results.

In France, image quality has been for years the first criteria in interventional radiology. Most of the procedures, even those performed on modern equipment, are not optimized. These results show that optimization is possible, with the willingness and involvement of all the actors.

Reference

C. Etard, P. Chabrot, JL Rehel, J. Guersen, L. Cassagnes, B. Aubert, L. Boyer, Poster IRPA 2012, Glasgow

5.3.3 Use of a Dedicated Pediatric CT Imaging Service Associated With Decreased Patient Radiation Dose

Issue

The growing use of CT as a diagnostic imaging tool has led to increased concern over radiation dose, particularly in pediatric patients. The ALARA concept has been popularized in dose reduction with the use of low-dose, pediatric-specific protocols. Strict adherence to low-dose protocols can be challenging, particularly in a high-volume radiology department that scans both paediatric and adult patients.

The aim of this study was to determine whether the relocation of pediatric radiology services from a combined high-volume pediatric and adult hospital to a children's hospital improves compliance with adjusted lower CT exposure parameters and thus the estimated effective dose of radiation delivered to pediatric patients.

Methodology

A retrospective review of abdominal and pelvic CT dose and exposure parameter data on 495 patients from a combined pediatric and adult radiology department and subsequently 244 patients from a dedicated pediatric radiology department was performed. The console dose-length product values were converted to effective dose. Patients were divided into 8 weight categories for the analysis.

A statistically significant decrease in the estimated effective dose for abdominal and pelvic CT studies was observed in all but one of the weight categories at the pediatric radiology department compared with the pediatric and adult radiology department.

Lessons learned

Imaging pediatric patients in a pediatric imaging department with dedicated CT technologists may result in greater compliance with pediatric protocols and significantly reduced patient dose. Conversely, greater scrutiny of compliance with pediatric dose-adjusted CT protocols may be necessary for departments that scan both children and adults.

Reference

Heather L. Borders, MD, Courtney L. Barnes, RN, BSN, MBA, David C. Parks, RT(R)(CT), Jerilynn R. Jacobsen, RT(R)(CT), Yong Zhou, PhD, Bruce E. Hasselquist, PhD, Bradford W. Betz, MDa in J Am Coll Radiol 2012;9:340-343. Copyright © 2012 American College of Radiology

5.3.4 Quality control and optimization of patient doses and image quality in the Norwegian Breast Cancer Screening Programme

Issue

Mass screening for breast cancer was introduced as a trial project in Norway in 1995. Due to promising results, the project was gradually developed into a national programme. As of early 2004, the programme covers the whole country. Organisationally, the Norwegian Breast Cancer Screening Programme (NBCSP) has both centralised and local functions. The latter includes performing the screening examination, and any further medical procedures if necessary. The stated objective is to provide the same high-level services for breast screening across the continent.

Methodology

The development of a system for quality assurance was given high priority during the early phase of the project. Working groups in quality assurance/quality control (QA/QC) were established for all relevant personnel groups (including radiologists, radiographers, pathologists, surgeons). Procedures for QA/QC were documented in a QA manual that has subsequently been revised regularly.

Responsibility for the quality control of physical and technical aspects of mammography screening was given to the Norwegian Radiation Protection Authority, who contributed two chapters to the QC manual: Constancy controls and status controls. The former includes frequent (i.e., daily, weekly, etc.) system tests and is performed by local personnel (radiographers). The latter consists of annual tests, and is performed by an inspection group from the NRPA.

The two chapters on technical QC set standards for equipment performance and acceptable dose levels. Mandatory reporting of constancy control results coupled with annual status control visits allows the NRPA to monitor the equipment performance status closely. Some of the recommendations and tests found in the QC manuals are directly or indirectly connected to at what dose level the equipment operates. Most importantly, a limit is set for the maximum dose allowed for the exposure of a "standard breast" under "clinical conditions".

For the last couple of years, and in accordance with national regulations, NRPA has been collecting exposure data from a representative selection of screening examinations. From these data, the doses to the screened women are calculated. Analysis of these data allows NRPA to pick up trends, compare with results from similar programmes in other countries, and identify areas or sites in need of further optimization.

As part of its mandate within the NBCSP, the NRPA has been actively involved in education, particularly of radiographers. Technical QC has been one of the main topics of a 7-day course that also covers epidemiology, anatomy, radiology, radiography, etc. It is strongly recommended that all radiographers working in the NBCSP complete this course.

Lessons learned

Prior to and in preparation for the mammography screening trial project NRPA conducted a survey of all mammography systems in use in Norway. Among the findings were that only about one third of the sites conducted some form of regular quality control and that the film optical densities varied considerably between the sites.

An increase in the implementation of quality assurance and quality control was recommended, as this was believed to have the potential to lower the number of deviations experienced. The need for national standards and recommendations in certain specific areas was also identified.

Partly due to the previous lack of medical physicists working in diagnostic radiology in Norway, the NRPA took on an expanded role in which it not only issued standards and collected survey data in relation to the screening programme but became closely involved in the practical work of conducting annual physics surveys and following up regularly on the quality control work being conducted by local staff. This has allowed NRPA to keep a closer watch on the degree to which the individual sites adhere to the standards than would otherwise have been the case.

Reference

Quality control and optimization of patient doses and image quality in the Norwegian Breast Cancer Screening Program, Kristin Pedersen and Gunnar Saxebøl, Norwegian Radiation Protection Authority, Norway

5.3.5 QA and optimization in diagnostic radiology: the benefits of a multi-disciplinary approach

Issue

Over the last 30 years, the technological developments in radiology and nuclear medicine have been tremendous, and therefore technological competence in hospitals is more in demand than ever. In future, the need for technologists in hospitals will increase, since technological development continues and the use of high-tech advanced equipment is increasing rapidly. They will also be needed for advanced hybrid surgical theatres where advanced radiological equipment is used during operations. Physicists are necessary to ensure the quality of equipment, optimize examinations with respect to radiation dose and image quality, develop new methods and implement new techniques. Diagnostic physicists must collaborate closely with radiologists and radiographers and other users of the equipment to ensure good diagnostic quality of the examinations. This multi-disciplinary collaboration, combined with the implementation of advanced technology in clinical practice, is making the work of a medical physicist especially challenging.

Methodology.

Oslo University Hospital (OUH) established a group of physicists specialized in diagnostic radiology, nuclear medicine and intervention, serving most of the hospitals in the south-eastern part of Norway in 2005. Today they provide a service to 35 radiological and nuclear medicine departments outside the OUH. This is a non-profit service; the salary for physicists and traveling costs related to the work done in a hospital are paid for by the receiving hospital. As far as possible, each hospital has one contact physicist working together with the radiologist and technicians in the radiology department, and multidisciplinary teamwork is one important factor of success. The services offered are:

- System acceptance tests
- Image quality and dose
- Quality assurance tests annually
- Multidisciplinary dose- and image quality optimizing projects
- CT
- Trauma
- Neuroradiology
- Intervention
- Pediatrics
- Lectures for surgical personnel using X-ray equipment
- Lectures for the radiological and nuclear medicine departments
- Dose measurements and dose estimates
- Consultancy in purchases of new radiology modalities

Furthermore, to improve optimization in Oslo University Hospital, a multi-disciplinary CT task group was established. The group meets every week to discuss optimal and sub-optimal CT examinations, radiation protection, and optimization of the examinations with respect to image quality and radiation exposure and the optimization of iodine contrast.

In 2008, CT colonoscopy was introduced at the hospital and, related to the introduction of this new technology, a task group consisting of radiologists, radiographers, physicists, and gastro surgeons and gastrologists was established.

Main results and lessons-learned

The economic benefits of a Regional Physicist Centre are that less personnel are needed because of recirculation of lectures, reports and knowledge between the physicists in the department. Also, less measuring equipment, phantoms, etc. is needed in the region due to a centralised pool of equipment.

Other benefits in the region are the enhanced competence in CT, X-ray, MR, and Nuclear medicine due to the exchange of experience and knowledge from different laboratories and hospitals. Technological problems are solved by experience from similar problems on other sites, and the development of QA methods and procedures are consolidated in the group of physicists.

The cooperation in the multi-disciplinary CT task group has resulted in several interesting follow-up projects that have contributed to further technological and clinical improvement. In particular they have resulted in new reconstruction algorithms for one CT vendor and improved technology for the automatic tube-current modulation for another vendor.

The multidisciplinary collaboration in CT colonoscopy resulted in the implementation of a new diagnostic method for the colon. It also resulted in a national course in CT colonoscopy for radiologists, gastro surgeons, gastrologists, radiographers and physicists. In addition, the Nordic CT-colonoscopy school that has been organized three times is a result of this multi-disciplinary collaboration.

Reference

QA and optimization in diagnostic radiology - a multi-disciplinary task: How to build a regional service to implement ALARA? Anne Catrine Traegde Martinsen, Hilde Kjernlie Saether, EAN Newsletter Issue 29, October 2011.

5.3.6 Action research regarding the optimization of radiological protection for nurses during vascular interventional radiology

Issue

One of the main issues to consider during interventional radiology procedures is the protection of the participating personnel (physicians, technologists, nurses, etc.) from the leakage and scattered radiation. A study was carried out, concerning actions to be taken in order to reduce the occupational exposure of interventional radiology (IR) nurses.

Methodology

During the research, four radiation protection improvement measures were continuously performed in cooperation with researchers, nurses and stakeholders:

- the dosimetry equipment was changed from one electronic personal dosimeter (EPD) to two silver-activated phosphate glass dosimeters (PGDs)
- the nurses were educated regarding maintaining a safe distance from the sources of scattered and leakage radiation
- portable radiation shielding screens were placed in the IR rooms, and
- the x-ray units' pulse rates were reduced by half

Finally, the annual effective doses of the nurses were compared before and after the implementation of the measures.

Results

According to the results of the study, the two PGDs recorded a 4.4 fold greater dose than the single EPD. However, educating nurses on radiation protection and reducing the x-ray units' pulse rates by half decreased their effective doses to one-third and two-fifths of the baseline dose, respectively.
The use of the portable shielding screens seems to have had no significant effect on the nurses' exposure.

Reference

Hiroshige Mori, Action research regarding the optimization of radiological protection for nurses during vascular interventional radiology, Journal of Radiological Protection, Volume 35, Number 2 (2015)

5.3.7 Application of risk-matrix methodology in radiotherapy

Issue

Radiotherapy is recognized to be a complex process, involving multiple professionals (oncologist, physicist, radiotherapy technician, etc.) and with the potential for accidental exposure. For these reasons, radiotherapy received special attention in both the IAEA safety standards and the Euratom Directive 2013/59 (article 63, Accidental and Unintended Exposures). In these documents, a systematic methodology is required to prevent events and identify vulnerable aspects of the process: the risk-matrix methodology in TecDoc 1685 is one way to achieve this. The Spanish regulatory body CSN (Consejo de Seguridad Nuclear) has translated this document and implemented the methodology.

Methodology & result

A 'risk' is defined as:

Risk = frequency, f (of an initiating event, expressed in year-1 for 500 patients) × probability, P (of failure of the safety barriers) × consequences, C (of the irradiation)

- It is proposed that the levels of frequency of the initiating event can be divided into 4 categories: High, Medium, Low and Very Low.
- The probability of failure of safety barriers (of technical and organisational nature) is also ranged into the same 4 categories.
- The scale of consequences that take into account both the severity and the number of patients affected, can be Very High, High, Medium or Low.

As a result, the 3 dimensions of the risk-matrix can have 64 different possible shapes (4 × 4 × 4).

In 2013, the CSN initiated the project of 'translating' an existing risk matrix evaluation software from the FORO network into a Spanish context. This work was made in collaboration with 12 reference hospitals across the country. As a result, three documents, including one practical guidebook, have been published.

The new software has been benchmarked against the SAFRON system data (SAFRON stands for Safety in Radiation Oncology and is the IAEA voluntary reporting and learning system of radiotherapy incidents and near misses). This benchmarking shows good results as the majority of the events reported in SAFRON matched with one or more initiating event included in the risk matrix defined for Spain.

The methodology allows the risk level for each accident sequence to be obtained easily. Sequences with high or very high risk-levels are to be selected for further analysis, while other sequences will receive less priority. According to the results, measures can be taken to reduce

- the frequency of the initiating event (e.g. lowering human error)
- and/or reduce the probability of barrier failure (e.g. robustness)
- and/or the consequence of accident (e.g. follow-up procedures).

New calculations can then be performed iteratively, until an acceptable risk is attained.

This methodology exemplified the identification of the "weak point" and the search for the most accurate and most efficient measure/measures in the specific case of radiotherapy.

Furthermore, as the method cannot be applied to evaluate *f*, *P* and *C* without the involvement of the whole team (i.e. the oncologist, the physicist and the radiotherapy technician), one indirect advantage of the method is that professionals have to communicate and discuss their procedures, the equipment etc. The software has also proven to be a good incentive for practitioners to advocate for improvement of procedures or equipment.

References

IAEA TecDoc Application of the Risk Matrix Method to Radiotherapy, TecDoc No. 1685, 2016.

Presentation made by Mr. Arturo Perez-Mulas (CSN, Spain) at the occasion of the 42th EAN Steering Group Meeting (November 2016).

5.4 Public exposure from planned exposure situations

5.4.1 Assessing doses to the public from discharges of radionuclides from non-nuclear establishments in the UK

Context and issues

Organizations disposing of radioactive wastes, including those making direct discharges to the environment, are regulated in the UK by the various environment agencies who enforce the provisions of the relevant radioactive substances' regulations. Where an authorisation (licence) to dispose of radioactive wastes is granted it will have a condition that the authorised undertaking (the "user") is required to use best practicable means ("BPM") to dispose of wastes in a form and manner that minimises the radiological effects on the environment and members of the public.

The BPM requirement means that consideration always has to be given to avoiding or at least reducing discharges, but this is not judged practicable in many cases and discharges take place which will give rise to radiation doses to the public and some disposal workers.

Typical direct discharges that occur in the non-nuclear sector in the UK include

- Discharges into public sewage systems of medical radionuclides such as iodine-131 and technetium-99m
- Discharges to public sewers of radionuclides used in laboratory research, typically tritium, carbon-14, phosphorus-32, sulphur-35 and iodine-125.
- Discharges to air from incinerators used to treat radioactive wastes.
- Discharge of gaseous radionuclides from cyclotrons (carbon-11 and fluorine-18).
- Occasional discharges to air and water air from industrial processes handling naturally occurring radioactive material (NORM) where activity concentrations exceed the thresholds for regulatory exclusion.

Discharges into public sewage systems are important as they will cause exposure of sewage workers, but also because all but the very short half-life radionuclides will pass through the sewage works and then into rivers and, in some cases, directly into the marine environment.

Methodology

The decision on what BPM means in any situation involves an element of radiological optimization where, at least in principle, direct and indirect costs of reducing or eliminating a discharge are balanced against the detriment associated with the radiation doses received as a result of the discharge.

However, it is clear that other broader factors such as public acceptability may influence decision making. However, if radiation dose is to be a factor in decision making then it is important to assess such doses in a reliable manner. If doses are likely to be very low then the accuracy of the dose estimates is not particularly important and some overestimating of doses is tolerable, but this is not the case where the assessment suggests that critical groups (those most exposed as a result of the discharges) may receive doses close to or even above the agreed dose limit or dose constraint.

As part of the process of applying for an authorisation where direct discharges are involved the user is required to provide to the regulator their own radiological assessment. This assessment is then subject to scrutiny by the regulator before a decision is reached. This requirement for the user to demonstrate

that doses from discharges are acceptable, rather than the regulator assume primary responsibility for this task, is an important element of UK practice in this respect.

The description so far would apply to both discharges from the nuclear sector and the non-nuclear sector. However, in the former case the discharge assessment is invariably undertaken by radiological specialists with access to the "best" models and with significant resources available. This tends not to be the case in the non-nuclear sector where the task of undertaking the assessment will fall to the Radiation Protection Adviser or similar persons at a hospital, university, or a research laboratory, although some users will use radiological consultants to prepare these reports. Another important feature of non-nuclear assessments compared to nuclear sector ones is that normally there is no expectation that environmental monitoring will be done, and so these non-nuclear dose assessments rely on calculations alone.

Where solid radioactive wastes are disposed to a specified landfill site then the user is also required to provide a radiological assessment. This type of assessment, although likely to predict very low doses for non-nuclear wastes, is technically quite challenging because of the need to consider hydrogeology features which affect groundwater movement and probabilistic events such as waste fires. However, there are currently very few authorisations that permit this disposal route in the UK and so such assessments are rarely required. (Solid wastes containing very low levels of activity can be authorised for disposal in normal refuse without specification of the exact disposal site. Users are not required to assess this on the grounds that dose will always be low and it is judged best to demonstrate this at the national level).

Reference

Assessing doses to the public from discharges of radionuclides from non-nuclear establishments in the UK, C. McDonnell. 11th EAN Workshop on "ALARA in Radioactive Waste Management", Athens, Greece, April 2008. (www.eu-alara.net)

5.5.1 Use of X-Ray body scanners in the UK and matters to consider to keep doses ALARA

Context

X-rays have been used for many years to screen baggage and postal items for illicit materials. In the last 15 years, larger versions of this type of technology have been developed to screen vehicles. Within the last 10 years, X-ray transmission equipment to screen suspected smugglers arriving at airports has been introduced, as have limited trials involving backscatter devices to screen passengers prior to flying.

Issue

At an airport, there are two categories of passengers who may be selected for X-ray examination:

- Passengers about to fly and transiting through security who, through profiling, may pose a greater risk to the flight, and
- Passengers who have landed and leaving the airport through customs control who, through intelligence or profiling, may be carrying illicit materials.

Examination of category A passengers is concerned with items that may be used for terrorist or criminal activity on the flight (fire arms, explosives, knives and similar) and many passenger may be selected to undergo such screening. This differs from Category B passengers since the examinations (carried out by custom officers) are concerned with narcotics and other illicit materials that may be brought into the country and involve fewer persons.

The use of transmission X -ray systems gives rise to greater dose (up to 5 μSv per examination) than backscatter X-ray systems (typically up to 100 nSv per examination). There is some medical justification for the screening of smugglers, since the item(s) swallowed may give rise to significant health effects if containment is breached, i.e. drugs overdose. This also enables customs officers to screen suspected smugglers at the airport instead of sending them to a hospital for X-raying.

In the UK, the use of this technology to screen passengers prior to a flight has not been explicitly justified. However, since backscatter X-ray screening systems were in use prior to May 2000, these systems may be used in the UK without the requirement of formal justification. Dose to screened passengers is much less than those screened by transmission systems but more people could be selected for screening.

Methodology

Means of optimising doses include:

- improved selection criteria to reduce the numbers of persons scanned,
- improved image processing to provide an acceptable image but with a lower dose,
- selection of operating parameters for transmission systems to optimise image quality against dose received,
- development of image test tools to avoid the temptation of using security staff or engineers to test the equipment,
- development of other non-ionising techniques to scan passengers (as a replacement to backscatter screening).

Main result

The screening of passengers and others for illicit materials is likely to increase in the UK but technological advances (for image processing and use of non-ionising techniques) and optimization of doses by careful selection of the operating parameters (kV, mA, time) offer the possibility that doses can still be kept ALARA.

Reference

Use of X-ray Body Scanner Equipment in the UK and matters to consider to keep doses ALARA, A. MacDonald 12th EAN Workshop on "ALARA issues arising for safety and security of radiation sources and security screening devices", Vienna, Austria, October 2009 (www.eu-alara.net).

6 ALARA IN PRACTICE FOR EXISTING EXPOSURE SITUATIONS

6.1 Occupational exposures in existing exposure situations

6.1.1 Management of NORM residues

Context and issue

Since 1928 Crotone was characterized by the presence of important Italian chemical industries that produced huge amounts of NORM residues. In particular the following activities are of radiation protection concern:

- production of phosphoric acid by the wet process (attack of phosphorites with sulfuric acid), used in fertilizer production; the process determines the precipitation of phosphogypsum;
- production of phosphoric acid by the thermal process; this acid is of a much higher purity and is also used in the manufacture of high grade chemicals, pharmaceuticals, detergents, food products and beverages. The main residues from this process are calcium metasilicates.

In the industrial plant area of Crotone about 5100 ton of phosphogypsum and lower but unknown amounts of metasilicates were produced. These residues were partly disposed of in landfills for inert matter, close to the seacoast and the mouth of the river Esaro, and partly used as filling material for roads, ports and yards due to their good mechanical properties. In the industrial port area of Crotone significant amounts of metasilicates were used extensively as filling material under a layer of about 20 cm of concrete. These residues came to the surface in a tract by the entrance pier due to a landslide caused by sea erosion. Stones of metasilicates of various sizes were present. As expected and confirmed by laboratory analyses, they showed high activity concentration of ^{226}Ra (770-1200 Bq kg^{-1}) and low activity concentrations of ^{232}Th and ^{40}K with mean values of 47 and 97 Bq kg^{-1}, respectively. In the landslide area (about 550 m^2) the presence of these materials led to a gamma dose rate of 590 ± 39 nGyh^{-1} at a height of one metre with a mean value of 266 ± 12 nGyh^{-1} to be compared with an average background of 95 ± 15 nGyh^{-1}. On the basis of these measurements, a more detailed characterization of the site was agreed, in order to proceed with an appropriate remediation plan.

Methodology

In order to characterize the site, assess the radiological impact and provide information for the remediation action plan, different measurements and sampling were performed:

- weekly air particulate sampling was carried out under prevailing wind with a high-volume sampler; relevant filters, for a total volume of about 7500 m^3 of air, were measured by gamma spectrometry and compared with background samples;
- at 28 points at the entrance pier area (about 1570 m^2) the material from the top 10 cm was sampled and analysed. In addition, to increase the representativeness of the sample, in some parts of the area samples of grass (500 g) were also collected;
- around any sampling point in situ measurements of gamma dose rate in contact and at one metre above the ground were performed and beta/gamma counts were recorded.

Main results

In order to determine the worker annual effective dose an occupational time of 450 hours, a breathing rate of 1.2 m^3 h^{-1} and a conversion coefficient Sv Gy^{-1} of 0.7 for gamma dose rate were assumed (4). The annual effective dose was estimated to be 0.23 mSv, consisting of 0.2 mSv and 0.02 mSv for gamma radiation and radon, respectively. The contribution from the inhalation of particulate dispersed in air was estimated as 0.012 mSv. The dose to the general population was not evaluated due to restricted access to the area.

The authorities ordered that remedial actions be carried out to reduce the exposure levels in the area of interest, but the quality and effectiveness of the chosen interventions were fairly low due to their temporary nature and being largely selected on the basis of cost-saving. For example, the landslide area was covered by high density plastic sheets and bags of silica sand to 15 cm thickness, to act as a shield for beta and gamma radiation. The intervention was effective for the beta radiation but reduced the gamma dose rate by only 20 %.

Lesson learned

The work and economic efforts employed by technical bodies to characterize the NORM contaminated site, providing a basis for appropriate remedial actions, were followed by inadequate and temporary (e.g. not weather proof) interventions. A global and adequately supported intervention would have permanently solved the problem without wasting work, time and funds.

References

I norm nel territorio di crotone: stato della contaminazione, stime dosimetriche e valutazioni radioprotezionistiche, S. Procopio, C. Nuccetelli. In Proceedings of the AIRP-XXXV Congresso Nazionale di Radioprotezione, Venice 17-19 October 2012. ISBN 978-88-88648-35-4.

Extent of Environmental contamination by Naturally Occurring Radioactive Material (NORM) and technological options for mitigation. Technical Reports Series no. 419. International Atomic Energy Agency , Vienna, 2003

Parliamentary Commission of Inquiry on illegal activities related to the waste cycle. Territorial Report on illegal activities related to the waste cycle in Calabria. Doc. XXIII n. 7. May 2011. http://parlamento.camera.it/_dati/leg16/lavori/documentiparlamentari/indiceetesti/023/007/pdfel.html

Legislative Decree No. 230 of 17 March 1995. Official Bulletin of the Italian Republic, ordinary supplement n° 136 of 13 June 1995

Sources and Effects of Ionizing Radiation: Volume I. United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR 2000 Report to the General Assembly, with Scientific Annexes United Nations, New York, 2000 (www.unscear.org/unscear/en/publications/2000 1.html)

6.1.2 Managing exposure in a company dealing with phosphogypsum

Context

Thermphos International BV manufactures elemental phosphorus out of phosphate ore ($Ca3(PO4)_2$). Impurities such as heavy metals and radionuclides are present in sedimentary phosphate ore. Uranium-238 is the main radionuclide found in sedimentary phosphate ore, which can have an activity ranging from 0.5 to 2 Bq/g (in equilibrium with daughters). During the electrothermal phosphorus production process, the radionuclides are unintentionally enriched: At the high temperatures prevailing in the furnace, volatile inorganic substances, metals and radionuclides evaporate and condense on dust particles. The dust is trapped in the electrostatic precipitators and is recycled via the clay suspension into the pellets. When they reach the furnace for the second time, the volatile inorganic substances, heavy metals and radionuclides evaporate again. In this way these substances are enriched in the precipitator dust cycle. High concentrations of these substances cause instability in the operation of the furnaces, so the system has to be purged to control the concentration. The purge unit produces calcinate (calcined precipitator dust) with enhanced concentrations of radionuclides (up to 1000 Bq/g ^{210}Pb), which is, therefore, radioactive waste. During the manufacturing of elemental phosphorous, dust enriched with ^{210}Po and ^{210}Pb is emitted to the air of the workplace.

Issue

Operators involved in the production of phosphorus are exposed to radionuclides (mainly the enriched ^{210}Pb and ^{210}Po) from the precipitator dust cycle. In practice, these nuclides are alpha- and beta-emitters and do not cause an external dose. To cause a relevant dose, there must be an intake of these radionuclides into the human body. In workplaces, such intake occurs predominantly by inhaling dust.

Methodology

Personal air sample (PAS) measurements were carried out to determine the dose to which workers in the phosphorus production plant are exposed. In the period 1984 to 1993, approximately 30 PAS measurements were carried out annually on workers most likely to inhale radionuclides. This number increased during the years to approximately 60. By taking more measurements at the same time at different places in a working area and comparing them with earlier measurements, taking the process conditions into account, it was possible to determine the exposure pathways by which the radionuclides from the process reach the workers involved. As a result, a number of measures were taken in order to reduce the dose.

Main results

In general, it can be concluded that workers involved in the production of phosphorus at the Thermphos site were exposed to an average dose of 1 mSv per year. This dose is not constant from day to day. There were days when the dose, extrapolated from one workday (the measuring period), yielded an annual dose of 5 mSv. On the other hand, there were also days that yielded an extrapolated annual dose of 0 mSv. The variations depend on the determined process conditions and working methods (exposure pathways).

The policy of Thermphos is aimed at dose reduction. The measures taken go beyond the essential minimum based on ALARA considerations and a Cost Benefit Analysis (CBA) value. Thermphos applies safety regulations aimed at preventing excessive doses. If a vessel, sintering disk or furnace has to be opened for inspection or repair work, the surface contamination has to be measured first and procedures are graded according to the result.

- If the contamination is below 0.25 Bq per cm^2, operators can enter without protective equipment.
- From 0.25 Bq per cm^2 to 10 Bq per cm^2, a FFP3 half mask must be worn. This mask has a very high theoretical (laboratory) protection factor (50). This is due to the sturdy construction and broad, flexible sealing edge. On the basis of BS 4275 BS EN 149, a protection factor of 20 is assigned. The Dutch labour/factory inspectorate specifies a value of 10, which is therefore also used by Thermphos in dose reduction calculations.
- Above 10 Bq per cm^2 a full-face mask with overpressure breathing air is prescribed. These limiting values for the surface contamination are conservatively derived from the results of the measurement programs. They apply to incidental work that does not produce excessive dust. If excessive dust is produced, a full-face mask with overpressure breathing air must be worn.

Lessons learned

About 200 operators and technical staff work in phosphorus production. The collective dose that this population receives in 25 years is 5 man.Sv. Assuming that an investment in improved working conditions would avert that collective dose, reasonable investment costs are about 750,000 €, based on the CBA value of £50,000 per saved man.Sv, as specified by the NPRB for occupational exposure. Higher values are also mentioned in literature.

The actions that have been taken are:

- Large-scale cleaning activities. New floors in the phosphorus plant with a top layer that is easy to keep clean. (Cost: 300,000 €).
- Central vacuum cleaning system (vacuum pipes through the plant with vacuum tube connection points) to simplify the work and to make the task of repeatedly emptying the vacuum cleaners unnecessary and avoiding the creation of more dust when full vacuum cleaners are emptied.
- Process automation to avoid work during which a dose is received and to prevent vessels from overflowing.
- Breathing air protection measures in situations where the creation of concentrations of radionuclides in the surrounding air is unavoidable.
- Continuous cleaning operations carried out by several cleaning operators.
- Improved ventilation, as in the vicinity of the ferro-phosphorus tapping point.
- The slag beds have been relocated from their position immediately beside the phosphorus plant to their current position well away from the plant.
- Measuring and monitoring programs.

In view of the fact that it is impossible to eliminate all exposure, the dose reduction due to these improvements is not the complete 5 man.Sv mentioned above but only a fraction of it. It is therefore evident that the improvements carried out are based more on considerations of "good housekeeping", "best available techniques" and "responsible care for the operators concerned" than on strict ALARA considerations with a CBA value.

It is concluded that natural radioactivity in a process like elemental phosphorus production may cause difficulties in the workplace, which cannot be ignored from a radiation protection point of view. However, these difficulties are manageable and dose can be reduced ALARA.

Reference

Erkens W H H ,2005. Phosphorus Production and Natural Radionuclides: Consequences for the Operators Concerned, W. H. H. Erkens, Themphos International presented at the occasion of the EAN 9th Workshop on Occupational Exposure to Natural Radiation, Augsburg, Germany, October 2005. http://www.eu-alara.net/index.php/activities/workshops/61-ean9.html

6.2 Public exposures in existing exposure situations

6.2.1 NORM legacy site

Issue

Two sites contaminated by NORM were found in the Hanover area. In 2008 an "existing exposure situation" was discovered, by chance, in the residential area around the "De-Haen-Platz" in the List village near Hanover. An ambient dose rate up to 15000 nSv h^{-1} (background 80 nSv h^{-1}) was measured, due to radiological contamination of soil with ^{230}Th, ^{226}Ra, ^{238}U and ^{232}Th. Chemical contamination of soil due to As, Pb, Sb, Hg/Cd was also detected. The radiological/chemical contamination originated from the foundation of the "Chemical Plant E. De Haen" in 1862 in Hanover-List. In 1865-68 a larger plant was built which produced inorganic chemicals at the site of the current contaminated ground. In 1902 the Company moved to Seelze near Hanover. Residues were transferred to north of List at Lister Damm, the other contaminated site, and disposed of. The disposal site was later developed into an allotment garden area.

Methodology

In Germany no specific radiation protection regulation for radioactive soil contamination is in force. The hazard assessment was performed by dose calculation according to the German "Calculation Guide Mining". The dose level to decide if remediation is needed is set at 1 mSv y^{-1} of effective dose for the general public.

Remediation planning was elaborated with three main goals:

- reduction of health risks to a long-lasting acceptable level according to criteria of soil protection regulations, i.e. 300-500 nSv h^{-1};
- the contaminated area had to be reused but in a restricted way as a parking lot for garden waste containers;
- measures had to be restricted to the essentials.

The proposed technical solutions to recover the area were:

- partial excavation of the contaminated soil to the necessary extent;
- disposal of the excavated materials to landfills;
- covering of remaining contamination by uncontaminated construction materials.

The different aspects of the technical execution were entrusted to different contractors. The company in charge of radiological supervision also had to manage waste produced by the remediation work. All activities were carried out under the control of the Radiation Protection Authority and the Trade Supervisory Office.

The main tasks faced by the radiological supervision and waste management company were to:

1. Determine the extent of excavation needed to ensure compliance with remediation targets but also minimise the amount of waste generated. The main criterion was to warrant a surface dose lower than 300 nSv h^{-1}. Therefore, the first action was to decide the excavation depth needed to ensure the dose would be less than 300 nSv h^{-1}, accounting for shielding effect of covering by uncontaminated construction materials. This required measurements of dose rates directly over the ground. The health and safety plan also included toxic substances (Hg, Pb, Sb, Cd,…).

2. Estimate the effective doses of workers. A preliminary estimation, based on the planned duration of the work, the expected work activities and the radionuclide activity concentrations, evaluated likely effective doses to workers to be less than 1 mSv y^{-1} making dose surveillance unnecessary. Some limited dose measurements with personal dosimeters were performed for particular workers, such as the "radiological supervisor". The results of this personal dosimetry confirmed the preliminary estimation with a maximum reported effective dose of 0.5 mSv y^{-1} for remediation workers.
3. Manage waste materials in order to ensure low doses to workers at the disposal site, by determination of *in situ* dose rate, and assigning waste to activity classes in compliance with the European rules for transport of dangerous goods by roads (ADR Class 7). Wastes were sampled and analyzed in a laboratory and classified into four classes accordingly to radioactivity measurement results, from Class 0 (uncontaminated waste to be given to a waste treatment facility) to Class 3 ("radioactive waste" disposed in the Federal State collecting facility for radioactive waste).

Main results

In 2011, a partial remediation of both sites was concluded. The resulting ambient dose rate is less than 500 nSv h^{-1} compared to the background dose rate of 80 nSv h^{-1}.

Lesson learned

A graded approach to the problem and the goal of a "partial remediation" to reach long-lasting acceptable dose levels enabled a fast and effective remediation for restricted use of contaminated areas.

References

BfS - Bundesamtes für Strahlenschutz, 2011. Calculation Guide Mining - Calculation Guide for the Determination of Radiation Exposure due to Environmental Radioactivity Resulting from Mining. Bundesamtes für Strahlenschutz, Salzgitter, September 2011.

Gellerman R, Nickstadt K, 2012. Radiation protection during the remediation of radioactive contaminated ground on former industrially used sites. 14th EAN workshop on "ALARA in Existing Exposure Situations", Dublin, Ireland, September 2012.
http://www.eu-alara.net/index.php/activities/workshops/274-14th-ean-workshop-on-qalara-in-existing-exposure-situationsq.html

UNECE - United Nations Economic Commission for Europe, 2012. European Agreement concerning the International Carriage of Dangerous Goods by Road (ADR 2013). ECE/TRANS/225. United Nations, New York and Geneva, 2012.

6.2.2 Managing radon at the level of a community of municipalities

Issue

The Community of Municipalities of Montbéliard (France) consists of 29 municipalities from villages to town, with a total of 125,000 inhabitants. The Community is managed by a council of 68 elected representatives, with competencies in the fields of economic, social, environment, health, education, etc.

With an estimated average radon concentration of 180 Bq/m^3, the "Pays de Montbéliard" is considered as a priority area by the government for reducing radon risk. The Community of Municipalities started a Project to reduce and maintain radon exposure ALARA in the Community. Several actors are involved in the project:

- Local actors: University, NGOs
- National actors: French Safety Authority (ASN), French Technical Support Organization (IRSN)
- International actors: Public Health Federal Office of Switzerland (OFSP), Swiss Romand Radiation Protection Association (ARRAD)

Methodology and results

Management of radon in dwellings

In 2005 it was decided to launch an awareness campaign on radon risk at the occasion of a "Housing Improvement Programme" proposed by the Franche Comté Region

- In winter 2006/2007, information meetings on radon risk were organised with the elected representatives of the 29 municipalities of the Community. A measurement campaign was conducted by the public hygiene officers in 350 private dwellings recruited by the municipalities
- In spring 2007, a presentation of the results to the concerned inhabitants was made by the mayors (mean value: 125 Bq/m^3, maximum value: 2000 Bq/m^3). The Community decided to support inhabitants with radon concentration above 300 Bq/m^3 in their homes: free radon measurements supported by the Community was offered as well as free remediation actions through an agreement with the National Agency for Housing Improvement
- In summer 2007, visit of dwellings with radon concentration above 300 Bq/m^3 was organised and advice given to the inhabitants to ventilate rooms usually occupied.
- In winter 2007, new measurements were carried out in dwellings above 300 Bq/m^3 and confirmed high levels in a few houses. IRSN and OFSP provided support to carry out radon measurements and to propose remediation actions.

Management of radon in public buildings

In 2007 The Community decided to measure radon concentrations in public buildings starting with a measurement campaign in schools. The steps taken included:

- Training of officers from the public hygiene office was organised to be certified for measurements.
- The first measurement campaign was undertaken in winter 2008/2009 in 57 schools: 3 schools were identified with radon concentrations above 400 Bq/m^3 (action level)
- Technical evaluation of radon sources was performed in the three schools in summer 2009 with the help of OFSP (Swiss) and new measurements during winter 2010 after remediation showing the following results:
    - School 1: reduction from 480 to 300 Bq/m^3.

- School 2: reduction from 1800 to less than 100 Bq/m^3.
- School 3: reduction from 1300 to 400 Bq/m^3.

Next steps

The project will continue in 2 directions:

- For dwellings: launching of a new campaign in autumn 2012 with the offer to inhabitants of a kit to make measurements themselves and receive advice online or on-site.
- For public buildings: start a measurement campaign in winter 2012/2013 in other public buildings than schools.

Reference

Isabelle Meraux Netillard, Sandra Biguenet, Jacques Lochard, Cynthia Réaud. The Montbéliard Experience with Managing Radon. 14th EAN workshop on "ALARA in Existing Exposure Situations", Dublin, Ireland, September 2012
http://www.eu-alara.net/index.php/activities/workshops/274-14th-ean-workshop-on-qalara-in-existing-exposure-situationsq.html

6.2.3 Natural radioactivity in building materials

Issue

The Czech Republic has some of the highest indoor radon concentrations in the world. Indeed, its mean radon value in dwellings is 140 Bq m^{-3}. In particular, from 1970, the Czech Republic had to face a serious situation with several thousand houses built with material rich in radium or contaminated by residues from uranium paint and radium factories. ^{226}Ra activity concentrations were measured up to 1MBq kg^{-1} and as a consequence the inhabitants were exposed not only to elevated radon concentrations but also to gamma radiation.

Methodology

In order to limit indoor exposure, in 1987 the Czech Republic introduced an ad hoc legislation stating interventional levels for existing houses. Below is the only example found in the literature of the use of an index to identify existing dwellings of concern.

For existing houses, the recommendation defined the following index S:

$$S = \frac{D}{2\mu Gyh^{-1}} + \frac{C_{Rn}}{400Bqm^{-3}}$$

where D is the gamma dose rate (μGy.h^{-1}) and C_{Rn} the long-term radon activity concentration (Bq m^{-3}). This index results from the choice of a recommended value of 400 Bq m^{-3} for radon activity concentration, and 2 μGy.h^{-1} for indoor gamma dose rate, to remediate these buildings. This rule was used only if D > 0.5 μGy.h^{-1}, and for S >1 remedial measures were supported by the government.

For new houses, a reference level of 200 Bq m^{-3} was stated for indoor radon. In order to keep ≤ 30% of the building material contribution to the indoor radon compared to soil contribution, the limit value for ^{226}Ra was calculated under conservative conditions to be 120 Bq kg^{-1}.

Main results

Most of the affected houses were remediated with governmental subsidy, and some of the costs were reimbursed completely.

Lessons learned

The use of the index S to regulate total dose in fact caused confusion in decision-making and some misunderstandings. It may be more appropriate to separate gamma dose rate and radon exposure for decision-making.

<u>The present regulation</u>

Since 2002 Czech legislation concerning radioactivity in building materials (Czech State Office for Nuclear Safety 2002) is now based on a two-step procedure to account for both gamma and radon exposure: firstly, the index I, as defined by the Radiation Protection 112 document, is used as a screening tool. Producers and importers should ensure systematic measurements of natural radionuclides in building materials and submit the results to the State Office for Nuclear Safety. If the index I is higher than 0.5 (a value corresponding to the exemption level of 0.3 mSv $year^{-1}$), a cost-benefit analysis should be done by the producer with a criterion aimed at reducing public doses to a level as low as reasonably achievable. This means that producers are not obliged to intervene if costs

of reduction of radionuclide concentration in building materials (e.g. change of raw materials, change of technology, etc...) can be demonstrated higher than the health detriment risks. In order to compare cost of reduction of radionuclide concentration in building materials and consequent benefits in terms of dose, a reduction of collective effective dose for a group of individuals assessed is multiplied by a factor of 0.5 million CZK/Sv. It is worthy to note that the dose criterion chosen is such that the majority of building materials on the market comply the requirements.

In the second step, in order to control radon exhalation from building materials, the producer must also apply the limit levels for ^{226}Ra activity concentrations shown in Table 4. Limit levels for ^{226}Ra (from Hůlka et al. 2008).

Table 4. Limit levels for ^{226}Ra (from Hůlka et al. 2008)

Type of building material	Limit value ^{226}Ra (Bq/kg) Occupied buildings	Limit value ^{226}Ra (Bq/kg) Unoccupied buildings
Material used in bulk amounts (e.g. brick, concrete, gypsum)	150	500
Other material used in small amounts (e.g. tile) and raw material (sand, building stone, gravel aggregate, bottom ash..)	300	1000

Lessons learned

The Czech experience after 30 years of application of regulation shows that it is possible to regulate exposures (gamma and radon) arising from natural radionuclides in building materials. Reduction of high indoor gamma dose-rates in existing houses can be difficult. Indeed the new regulation, based on the ALARA principle, is aimed to reduce exposures in new buildings.

The authors of this text are very grateful to Jiří Hůlka, National Radiation Protection Institute, Prague, Czech Republic for his help in writing down this example.

References

European Commission Radiological Protection Principles concerning the Natural Radioactivity of Building Materials, European Commission, Radiation Protection No.112, 1999

Jiří Hůlka, Jaroslav Vlček, Jiří Thomas. Natural Radioactivity In Building Materials - Czech Experience and European Legislation. Proceedings of the American Association of Radon Scientists and Technologists 2008 International Symposium Las Vegas NV, September 14-17, 2008

Czech State Office for Nuclear Safety. REGULATION No. 307/2002 Coll. on Radiation Protection

6.2.4 Example from phosphogypsum sites

Context and issue

In Italy from the end of the 1950s up to the early 1990s, some industrial plants located by the sea processed huge quantities of phosphorites for phosphoric acid production. Phosphogypsum wastes – such as slurry - were produced at a rate of some 105 t y^{-1} and disposed of in the sea until the mid 1970s. After that time, phosphogypsum was collected in landfills within, or close to, the industrial areas. In the early 2000s the Ministry of the Environment asked ISPRA (Istituto Superiore per la Protezione e la Ricerca Ambientale), INAIL (Istituto Nazionale per l'Assicurazione contro gli Infortuni sul Lavoro) and ISS (Istituto Superiore di Sanità), (research and technical bodies entrusted with radiation protection tasks), to analyse the remediation plan for a site in Sicily.

A working group (WG) was formed by experts from each of the three technical bodies to provide advice about: the existing landfill for phosphogypsum residues (located a few kilometres from the plant and a few hundred metres off the seacoast); the dismantling and remediation of the production plant; and the demolition of the three stores for the phosphorites.

For this situation, where past work activities have left heavy environmental contamination and a huge quantity of wastes, the factors considered by the WG when designing a remediation intervention can be summarised as follows: i) industrial plant decommissioning; ii) waste management; iii) landfill management; iv) radiation protection of the population and workers involved in the intervention; v) environmental protection; vi) law requirements relevant to chemical and radioactive contamination.

Methodology

Many efforts of the WG were devoted to convincing the Ministry of Environment that by-products/residues coming from a work activity with NORM should not be considered as radioactive waste (IT Dl.vo 2000, EC 1996, IAEA 2013). Another action of the WG was explaining to the Ministry of Environment that a radiological remediation intervention must be a global plan, justified and optimised - taking into account the minimization of doses to the general population and workers -, and that this approach cannot be limited to some specific topics such as the technical aspects of decommissioning.

Main results

With regards to the existing landfill site (which is close to agricultural settlements, just outside the very large industrial area that includes the production plant) the Ministry of Environment decided, on the basis of the relevant law, to remediate it without removing residues. This approach requires long-term surveillance of the site and maintenance of barriers, as well as long-term restrictions on land-use (e.g. banning of house building or other burrowing activities that could affect the integrity of the closure cap). An area of the landfill (10 hectares out of 55) was devoted to a solar power plant that started to work at the end of 2012. After the decision was made to maintain the residues in the restricted use landfill, the WG rejected the proposal of dismantling the plant with the complete decontamination of all the materials: indeed, the Ministry of Environment had proposed to clean all the remaining buildings and industrial structures completely in order to dispose them among general waste and to send the residues to a radioactive waste disposal. The technical institutes advised the Ministry that this solution was not optimised from the radiation protection point of view and would entail the unjustified exposure of workers. A new demolition plan was prepared which minimized manipulation. The best choice – in order to reduce the total volumes to be disposed of – was to distinguish the materials that can be easily

decontaminated from highly contaminated materials that, being of the same nature, could be added to the landfill. After some discussion, the proposal was accepted by the Minister of Environment.

Lessons learned

The above considerations show that an urgent problem to be solved at the national and international level is the harmonisation of legislation regarding conventional and NORM contamination. This view is also supported by the European ALARA Network (see recommendation no. 2 of its 7th Workshop on Decommissioning and Site Remediation", ref. 18). Indeed, about the integrated risk approach it was stated:

"An integrated (or 'holistic') approach to risk management in decommissioning and site remediation should be encouraged by international bodies such as IAEA, NEA and EC. This should be supported by regulators and implemented by operators, and should aim to include:

- a simultaneous consideration of (radiological and) non-radiological hazards and risks, so as to provide the best overall protection of persons and the environment;
- greater emphasis on life-cycle planning, where the issues of decommissioning and remediation are considered throughout".

Another lesson learned is that when the procedures to be followed are not yet determined, and the agreements to be reached are rather complex, the creation of a working party among experts of different institutes in order to issue joint official advice can be an highly effective experience.

Reference

Paganini Fioratti M, Magro L, Nuccetelli C, Risica S, Simeoni C, Giancarlo Torri G, Trevisi R, 2007. Remediation interventions in Italian industrial sites contaminated with NORM from the phosphate industry; law provisions, criteria and methods. Proceedings of 5th International Symposium on Naturally Occurring Radioactive Material - NORM V Conference, Seville, Spain, 19-22 March 2007.

6.2.5 Methodological guidelines for the management of industrial areas potentially contaminated by radioactive substances

These guidelines have been produced by the French Institute for Radiation Protection and Nuclear Safety (IRSN), the French Nuclear Safety Authority (ASN) and the French Ministry of Environment. After a first version in 2001, a revision was published in 2011.

In this guide, a clear distinction is made between polluted areas where uses are established and those without use or at redevelopment stage. When the uses are established, an "Interpretation of the condition of environment" is conducted. Alternatively, the remediation process follows a "management plan". Whatever the remediation process, site characterisation is required as soon as pollution is suspected. It includes literature reviews and field investigations primarily to confirm or deny the presence of pollution and, where appropriate, to determine its location, nature and level. The effort afforded to site characterisation must be proportionate to the identified issues.

Where uses are established: assess the compatibility between the level of pollution and the uses through the interpretation of the condition of environment (IEM)

- The first step consists of comparing the radiological levels of the potentially polluted areas to background or reference levels. When pollution is confirmed, assessment of compatibility between pollution and uses is based on the comparison of pollution or exposure levels to national threshold values established for the protection of people and the environment.
- Regarding pollution by radioactive substances, some threshold values set a reference level for a particular medium and the intended use. In that case, results of field characterisation can be directly compared to these threshold values. When such a reference level is not available because either the radionuclide or the compartment of the environment is not subject to regulation, dose assessment is required. A tool describing the way to conduct a dose assessment and the general and mathematical descriptions is proposed in the document. To judge the compatibility of the use and the level of pollution, the result of dose assessment has to first be compared to the reference value of 1 mSv.yr-1 set down in the French health code. This value constitutes a reference and options for reducing exposure have to be considered in application of the ALARA principle. Depending on the context, administration may impose lower dose thresholds, for example when pollution affects areas used by babies, children, patients...
- Finally, comparison of site characterisation results, and when necessary dose calculations, to threshold values, assists in identifying whether the existing populations are compatible with established uses, or to conclude there is a need for remediation.

Where uses are not established: design a remediation plan with the objective of lowering exposure through a management plan

- When uses are not established or when pollution is not compatible with existing uses, remediation has to be undertaken to lower the exposure. This can be achieved at first by reducing the sources of pollution (eg removal of the sources) or, when necessary, by limiting pollution and exposure pathways.
- When removing all the pollution is technically or financially not realistic, options limiting exposure are required and the land uses have to be adapted to the level of remaining exposure. Separately or combined, partial clean-up, containment of pollution, adaptation

of the redevelopment project to the residual pollution to limit exposure pathways should be considered.

- Different remediation options have to be considered in accordance with the applicable principle of optimization used in radiation protection taking into account the characteristics of pollution, the nature of existing or planned land uses and the remediation project. With regard to the added effective dose, the management objective is to be chosen as low as possible below the 1 mSv/year value.
- The cost-benefit balance is achieved by comparing various management strategies in order to select the best solution. This evaluation should be documented as evidence of the decision-making process used to reach the preferred option. It is particularly suitable to test, in consultation with stakeholders, the relevance of the assumptions so as to verify that the optimization process was conducted properly. It must lead to a consensual management.

Reference

"Guide Méthodologique – Gestion des sites potentiellement pollués par des substances radioactives", Ministère de l'Ecologie, du Développement durable, des Transports et du Logement, IRSN, ASN, Décembre 2011.

6.2.6 The raising of a radiological protection culture in a post-accident situation - The ETHOS project

Context and issue

As a result of the Chernobyl accident, 70% of the released radioactive material fell on the territories of the Republic of Belarus. Around 120,000 people were evacuated and 360 villages or settlements ceased to exist. Around 60% of the forest, the agricultural land and residential areas of the Gomel region (south-west of Belarus) were affected by the radioactive contamination.

Started in 1996, the ETHOS Project, supported by the European Commission, aimed to explore new strategies for the management of post-accident situations. The project was implemented at Stolyn Distict (Gomel region). The first conclusion of the project stated that inhabitants of the district have lost confidence in the authorities and experts and globally misunderstand the radiological conditions. Local people described their strong worries about health – especially for children – and their feeling of helplessness and abandonment.

Methodology

The ETHOS (and its follower the CORE project) approach was first based on listening to and learning from villagers about their concerns and priorities. Working groups gathering local people and radiation protection experts from Europe were set up on specific issues: protection of children, production of clean foodstuffs, education on practical radiation protection at school etc.

- Regarding external exposure, instruments were provided to the people to measure ambient dose rate and establish local mapping (house, garden). Discussion with locals helped to interpret the measurements and to identify the exposure characteristics. The external dose can then be evaluated. At Olmany village, a local external dose reference level was set at 1 µSv/h (around 9 mSv/y). External dose mapping was also an important input for the management of pastures and the growing of foodstuff.
- Regarding internal exposure, measurements of local food enabled the classification of products according to their ability to concentrate radionuclides (e.g. mushrooms and berries appear to particularly concentrate ^{137}Cs). Some products were considered relatively safe whilst others required regular follow-up (this is still the case for mushrooms). A local ingestion dose reference level of 300 Bq/day was set up at Olmany (around 1.3 mSv/y). Possible methods to limit internal exposure were proposed, evaluated and the results broadly communicated. For example, the effects of pre-cooking techniques on mushrooms have been evaluated: skinning and washing lead to a relative reduction of ^{137}Cs concentration of 40%, pickling 10%, preserving 10-20% etc.
- The identification of the most exposed children (through the use of Whole Body Counting at Stolyn Hospital) and discussion with the families was performed to identify the main source of internal contamination.

Later on (2004 – 2008) and based on the experience acquired, a radiation monitoring system (see Figure 1) was implemented in the Bragin district, close to Stolyn district. 6 centres for the measurements of foodstuffs (spectrometers or radiometers) were installed in villages; the local hospital was equipped with Whole Body Counting equipment. The aim was to provide access for measurements to every inhabitant and allow the population to participate to its own protection and regain self-control on its environment.

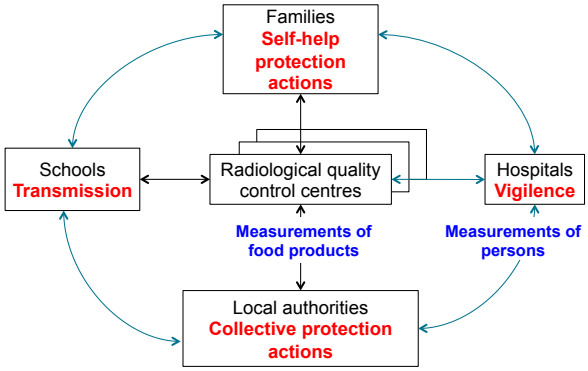

Figure 15. Radiation monitoring system implemented at Bragin district.

Results

The radiation monitoring system is still in use today – and it has been technically updated. Local people are used to check their food/produce for contamination before consumption. Whole Body Counting shows very little contamination (< 0.05 mSv/y) overall (noting that the level of environmental contamination has not significantly reduced since the implementation of the system).

The communities have integrated the issues of radiation protection: they are common topics of discussion and the basis of the work in dedicated village clubs. An annual health fair underlines the elements of importance for healthy living: managing contamination and exposures, but also eating well, practicing sport etc. There is a focus on safe ways to cook food and healthy eating using products grown in private gardens. A fair is also a way of removing the stress associated with living in contaminated territories.

Lessons learned

This experience shows the steps of the ALARA process that can be applied in a post-accident situation: description of the exposure situation and identification of the main contributors to dose, identification of the most exposed individuals that will require special focus, evaluation of the effectiveness of actions taken etc. In this situation, it appears that the ALARA process is less based on technical knowledge (even if the health education should be based on evidence that requires scientific knowledge: dose rate, internal contamination – which are objective parameters) but more on dialogue, sharing and confidence.

The approach demonstrates that the direct involvement of local stakeholders in the day-to-day management of a post-accident situation is feasible and evidenced by the potential for implementing protective actions, both at individual and collective levels.

References

Material presented at the occasion of the "Late Phase Nuclear Accident Preparedness and Management" training course, September 21 – 25 2015, Gomel, Belarus and organised by Radiation Protection Evaluation Centre (CEPN, France) and The Research Institute of Radiology (RIR, Belarus).

Application of the Commission's Recommendations to the Protection of People Living in Long-term Contaminated Areas After a Nuclear Accident or a Radiation Emergency. ICRP Publication 111. Ann. ICRP 39 (3), 2009.

6.2.7 Radioactive geological specimens

Context and issue

The collections of geological institutes and companies, museums or educational institutions very often contain minerals, soil samples or fossils with elevated content of natural radioisotopes, e.g. radioisotopes from the uranium and thorium series. When such minerals, fossils or specimens are put together, i.e. thousands of items in a same room, the elevated gamma dose rate can be significant, even more than 40 μSv/h. In addition, very often items are hidden in showrooms, namely placed below the visible part of showcases. Such items can be also found in corridors, offices and laboratories of universities as well as in cellars and storage areas. Workplaces can exist near such items. Due to the legislation used in the past, the majority of owners do not have the knowledge to safely handle radioactive items and as a rule do not have instruments to identify the radioactive items. As a result, persons, e.g. engineers, guardians in museum showrooms as well as students and other employees, can be exposed to quite high gamma dose rates as well as to radon gas. Loose contamination can be also present when handling very fragile items e.g. fossil wood, bones, soil samples.

Methodology

The identification of radioactive items was conducted by inspectors with full authority to access all premises of an institution. At least two independent experts conducted inspections of each item using different instruments. All items of concern were identified. Requirements regarding safety were put in place. Inspection by the regulatory authority was followed by a visit of qualified experts who repeated the measurements and assessed the concentration of specific radionuclides in each item. The legal part of the process, e.g. registration of sources, was based on the legislation.

Results

Owners of items decided which items needed to be retained for the purposes of institutions, e.g. geological companies, museums. The decision-making process took months because many stakeholders were involved, e.g. legal offices of companies, numerous professors and assistants at universities. Finally, as a rule only a small number of the radioactive items were returned to their original location. In such cases, they were stored or exhibited using appropriate safety measures, e.g. Pb glass, ventilation. In addition, a special regime for use of a small number of retained radioactive items in classrooms was put in place, e.g. separate storage of items to be brought in the classroom before use. The majority of items with activity concentrations above exemption levels were either transferred to storage for radioactive waste or put in secured and shielded places where no persons had a permanent working place. The radon issue and contamination of workplaces was carefully taken into account. Access to the items was controlled and an overall safety regime was put in place. One of the main measures was the training of staff. In addition, staff were informed that appropriate control must be taken over incoming items.

Lessons learned

- The gamma dose rates related to NORM specimens in geological companies, museums and universities could be well above background due to the fact that thousands of radioactive items could be held in a single room. Concentration of radon can pose a radiation protection issue. Possible contamination of workplaces due to fragile specimens can exist.
- The knowledge about elevated gamma dose rates, radon issues and possible contamination due to radioactive NORM specimens can be insufficient at such institutions.

As a result, no measures related to safety are in place, e.g. no database of radioactive specimens exist, no instruments available for measurements.

- The identification of such items cannot be done without full authorisation of the regulatory authority to access all premises. The past activities of institutions should be taken into account e.g. geological specimens can be retained by many institutions not only by museums.
- Strong cooperation between the owners of specimens and qualified experts should exist. The data regarding radioactive items can be scarce. The model should be used in order to establish activity concentrations for each item. Radon measurements should be undertaken if appropriate. The assessment of each radiological situation can be not only demanding but also a time-consuming task.
- As a rule, the owner should have enough time to make a decision concerning the need for future ownership of radioactive specimens.
- The owners should be aware that specimens obtained in the past can be radioactive so a screening procedure is necessary. In addition, also new items can be radioactive, sometimes acquired as a gift to a museum or a university and could arrive to an institution via the normal post. As a result, a strict procedure for taking ownership of new radioactive specimens should be in place.

Reference

Example provided by Dr Helena Janzekovic from the Slovenian Nuclear Safety Administration

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7 ALARA IN PRACTICE FOR EMERGENCY EXPOSURE SITUATIONS

7.1 Occupational exposure in emergency situation

7.1.1 A radiation protection approach in case of emergency

Issue

Following the analysis of the feedback of the Fukushima accident, the need for a better planning and organization of the deployment of Areva internal force in the event of a radiological emergency was pinpointed. As a result, the *Force d'Intervention Nationale d'Areva* (FINA) was created and embedded in the emergency organization of the company.

The objective of the FINA is to bring to an installation facing a radiological emergency all the human and materials needs within 48 hours.

Methodology

Different mission scenarios are drafted. These missions are defined in conjunction with the recent safety re-evaluation performed across Europe following the Fukushima accident. For each mission, a "mission sheet" describing the needs and an "answer sheet" describing the dedicated deployment actions have been elaborated. The missions of FINA's personnel are related with assistance to the installation staff, performing radiological measurements and control, physical protection of the installation etc. The personnel will work in collaboration with Areva local emergency staff and personal from INTRA Group (who manage the robotics).

After a mission, the staff will undergo a specific medical examination, with a special focus on internal contamination. If necessary, psychological support will be provided (decision will come from the health physicist).

A FINA team is composed of around 70 personal:

- Management: 8 – a radiation protection senior officer is embedded in the management.
- Intervention team: 32,
- Logistical support: 10,
- Engineering: 10.

The team is composed of:

- Category A voluntary employees of Areva (radiation protection staff, security staff and medical staff).
- They are informed about the working conditions.
- They have signed a specific agreement. This agreement notably presents the radiological conditions of intervention for each employee.
- They have performed a full body spectrometry less than 1 year before the event.
- And finally have received less than 5 mSv on the last 12 rolling months.

The FINA team is divided in 'division. A system of change in shift of the division is planned with the objective of dose management.

- A health physicist specialized in radiation protection is integrated in the FINA team.

- A Competent in Radiation Protection (French equivalent of the Radiation Protection Expert/Officier) is also present.
- Radiation protection technician or engineer are integrated in each division.
- Workers are fully equipped to perform their missions and have access to all the materials to measure contamination and exposure (individual and collective).

When it comes to on-site limitation of exposure, Areva has developed a filtered containment venting supported by monitoring system which provide detailed information. On-line containment atmosphere monitoring system HERMETIS perform observation of combustible gas and identify molten core/concrete interaction situation. The PASS system provides detailed information about the radionuclides in the containment allowing optimization (for example optimal time frame for using mitigation measures).

- A 'maximal dose limit' is selected for each FINA workers and 'contractualize' in the documents related to the intervention.
- Daily, weekly and monthly dose limits can also be defined and contractualize for a better follow-up and optimization of the exposure.
- Everything is made so the internal exposure tends to 0 mSv.
- Except exceptional circumstances, mask cannot be wear more than 4 h/day in total. The duration will be chosen after consideration of the circumstance (temperature, …)

The radiological zoning and surveillance of the French Law apply. A more detailed doctrine related to the application of the radiation protection is currently under elaboration.

Lessons learned

The radiological approach of the FINA is in fact greatly inspired by the approach for occupational exposure in planned situations. The FINA was deployed in 2011 when Areva workers set-up the first Fukushima water treatment facility (ACTIFLORAD). It was considered as successful as exposures were in agreement with the French law. The organization will be regularly tested during emergency exercises and could evolve according to the feedback.

References

Areva: Intervention de la FINA et Radioprotection des Travailleurs, B. Adhemar, D. Chanson, P. Devin, presentation made at the occasion of the seminar Radiation Protection of the workers in emergency situations organized by the French Society for Radiation Protection, March 2015.

Areva's Technology for Reduction of Radiation Impact in the Case of Severe Accident in NPP, M. Welker, poster elaborated at the occasion of the ISOE Symposium held in Brussels, June 2016.

7.1.2 ALARA approach of first responders to malevolent acts – German example

Context and issue

Radiation protection for first responders to malevolent acts involving radioactive materials is of utmost importance. The integration of radiation protection into the response to such an incident is central to its success. In Germany, the defence against nuclear hazards is normally the responsibility of the state ("Bundesland") in which an incident occurs. Each German Bundesland has its own police force, criminal police office and radiation protection authority who are all equipped to deal with small to medium-scale incidents involving radioactive materials. However, if the incident is of a serious and/or criminal nature, for instance an emergency with nuclear material or an attack with a radiological weapon, the Bundesland can call on the federal government for additional forces from a unit known as the "Federal Support Group for serious incidents involving radioactive materials" (abbreviated to ZUB from the German). The ZUB includes specialists from the Federal Criminal Police Office (BKA), the Federal Office for Radiation Protection (BfS) and the Federal Police (BPol).

When called upon, the ZUB is integrated into the local task force dealing with the threat. The control of the operation remains in the hands of the local Bundesland police administration. As every Bundesland has different ways of dealing with nuclear hazards, different regulations and specialists, it is crucial for the federal forces to remain flexible, whilst still allowing for the radiation protection under the BfS to take a central role in the deployment.

Methodology

Although the exact deployment scenario is difficult to anticipate, the radiation protection strategy envisaged by the BfS in the case that the ZUB is called upon to support regional police operations follows the As Low As Reasonably Achievable (ALARA) principle. A team of radiation protection officers from the BfS act as first responders within the ZUB and are able to make on-site measurements, dose estimates and immediate radiation protection recommendations. A team of BfS experts act in support of the first responders and can decide on the next steps for optimising the radiation protection (e.g., if more measurements are necessary or if additional equipment is required). The operational structure ensures that the radiation protection advice is timely, deployment-specific and central to the operations plan. The structure also ensures that the advice is communicated to all deployed forces through police channels and to the public via press conferences and statements.

Dose limits will be observed during a deployment of the ZUB.

- The dose limit for the public and for other first responders who do not routinely work with radioactive materials is 1 mSv per year.
- First responders within the ZUB who do routinely work with radioactive materials, i.e. the radiation protection officers and measurement teams from BfS, are allowed to receive a dose of up to 20 mSv per year due to routine operations. Their dose will be overseen and minimized as far as reasonably possible by a senior member of the radiation protection team at the scene, who has access to radiation measurement data and who can make informed and timely dose estimates. The goal is as low a radiation dose as reasonably attainable under deployment conditions
- In order to save lives (or to prevent serious harm to people or catastrophic events developing), an exceptional radiation dose of up to 250 mSv (once only, or 100 mSv in a year) as a reference level has to be observed, depending on the informed consent of the first responder involved and the permission of the senior radiation protection officer in charge.

The ZUB has a training schedule that includes both training and exercises internally within the ZUB (between BPol, BKA and BfS) on two different levels.

- The first level is training and exercises within one of the partner institutions, organised by that institution for its employees alone. A good example example would be internal BfS measurement exercises, where teams of experts measure, identify and quantify radioactive samples using the same equipment as available in a deployment.
- The second level of training and exercises internally within the ZUB occurs between the subgroups of the different institutions. Examples of this kind of training are: lecture- based education on radiation protection for all non-BfS ZUB staff, organised by the BfS; crime scene work exercises between forensic experts and radiation protection specialists; training police in how to use specialised radiation protection equipment and training BfS staff on police procedures and equipment.

Lessons learned from application in the field

In late 2006 the city of Hamburg in Northern Germany was faced with a potential dispersal of radioactive Po-210. At the time, the presence or scale of the dispersal was unknown, leading the city of Hamburg to call on the German Federal authorities for assistance in the form of the ZUB.

Although the deployment of the BfS as part of the ZUB and the deployment of the ZUB itself in Hamburg from 8th to 22nd December 2006 were successful and at no time were any members of the emergency services or the public at risk from the health effects of radiation the problems caused by poor communication during the deployment illustrate that the difference between the perceived harm caused by radioactive materials can be much greater than the actual harm caused. These differences in separating the perceived from the actual harm caused (or risks involved) with Po-210 were felt in three main areas of communication, namely: the internal communication between the different organizations; the external communication with the public and press and the discrepancies between the internal and external communication. The consequences of poor communication during a deployment are at the very least a loss of trust of the public and emergency responders, heightened anxiety and strains on health physics resources. In the worst case, poor communication of the radiation protection measures to be undertaken by the public and deployment forces could lead to deterministic radiation doses or to loss of life. This means that effective communication should be considered vital to ensure the ALARA principle is followed during a deployment

Lessons learned

Radiation doses during serious incidents involving radioactive materials should be minimized not only to reduce primary risks due to radiation exposure for first responders and the public, but also to help reduce the psychological trauma inflicted by the incident. In order to achieve this aim, radiation protection not only has to be ensured through the integration of radiation protection experts into the heart of the deployment infrastructure, but the radiation protection information must be effectively communicated.

Communication should be treated as vital to the success of a deployment and considered within the emergency planning well in advance of a deployment. Based on the evaluation of the Hamburg deployment, a new ZUB communication strategy has been put in place that emphasises a customised, homogeneous and appropriate (made-to-measure) response. The strategy includes information material for pre-deployment briefings and information cards for first responders and the public

Minimizing the radiation exposure risk during emergency situation management due to malevolent acts is a large task that involves a lot of preparation and planning. The radiation protection education of non-expert staff, joint training and exercises of emergency responders and the collection of pre-prepared information material for the deployed forces and the press is time consuming and costly. However; the benefits of the investment will be seen clearly if these efforts lead to the deployed forces and members of the public following the radiation protection advice, as this will contribute greatly to allowing the ALARA principle to be adhered to in a deployment situation

Reference

Minimizing the Radiation Exposure Risk of First Responders during Emergency Situation Management, R. Maier, E. Kroeger, BfS, presentation made at the occasion of EAN 9th Workshop, Vienna, 2009.

7.1.3 SaTu – Support System for Radiation Expert

Context and issue

During reactor accidents, it is important to be able to make estimates on radiation levels at the plant site and on the releases of radioactive fission products into the close environment. The radiation levels are especially important when considering accessibility of different control centres, and thus the possibility of performing specific accident management measures and operations aiming at repairing failed equipment.

The calculations needed to make these estimates are often rather lengthy and time-consuming, and therefore a simpler support system, focused to the most essential issues and easy to use in case of accident, was needed. This kind of system would allow the radiation experts to concentrate on more important issues, such as considering counter-measures in order to avoid high radiation doses at the plant site and in the vicinity of the plant. To manage the issues above, a support system for radiation experts (*Säteilyasiantuntijan tukijärjestel- mä* in Finnish) SaTu has been developed.

Methodology

The approach in SaTu is to describe the fission product release from the core and transport in the primary circuit, in the containment and in some other areas outside the containment (see Figure 1) with rather simple models. The basic idea is to calculate the transport in consecutive compartments by assuming constant source (*S*) and removal rate (*k*) for each compartment within one time step. The source is formed as a combination of the release from the core and the fission product flows from other compartments, and averaged in each time step.

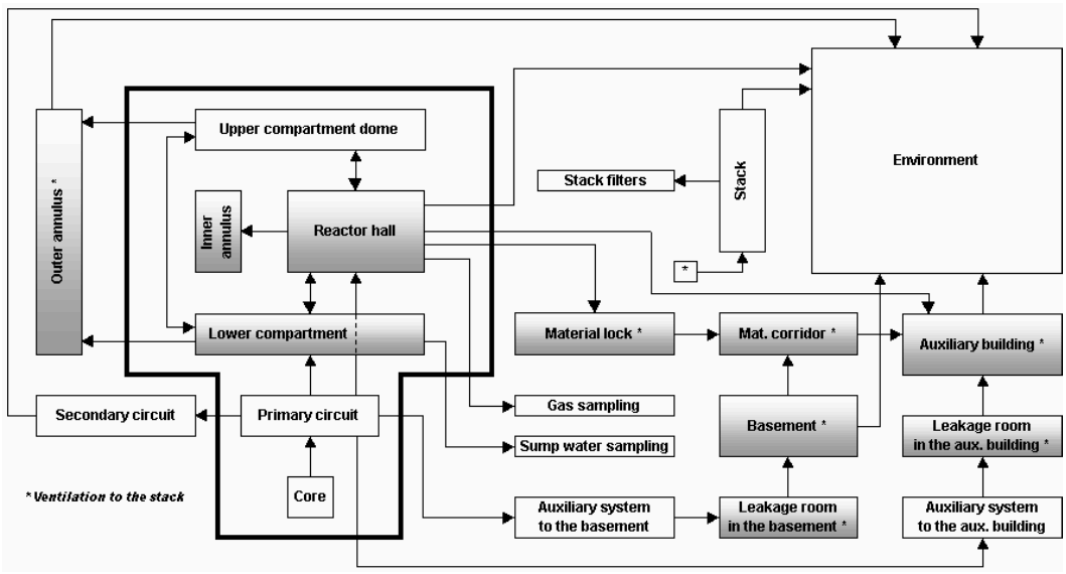


Figure 16. SaTu box flow charts

The fission product release from the core is estimated from the information on the core exit temperatures and depressurisation of the primary circuit. The release fractions are based on MELCOR calculations on several severe accident sequences for the plant. As the SaTu system is meant for the

first hours and days of a severe accident, a limited number of fission product groups are included in the system. Noble gases, iodine, caesium and tellurium are considered adequate and optimized for estimating the radiation levels at the plant site.

Several parameters affecting the fission product behaviour are implemented in the system, but they are not visible for the user. The amount of information that the user needs to provide is kept rather limited, and the most important parameters come from the plant measurements. The required measurements are part of the overall severe accident management scheme, and have been adequately qualified for severe accident conditions. For example, the time dependent information includes the sump water levels, containment internal spray flow rate, containment pressure and leakages, and airflows outside the containment. These affect the fission product transport in the containment and in the buildings outside the containment, as well as release into the environment.

SaTu system is built on several Microsoft Excel spreadsheet workbooks including some essential parts as Visual Basic code. This brings advantage, as Excel applications are familiar to the user group, and thus the user interface can be built quite easily.

The radiation level calculation includes direct and skyshine radiation from the containment, radiation levels in the buildings outside the containment due to activity inside the buildings themselves, and radiation from the fission products in the piping either as deposits on the piping surfaces or in the water flowing in the pipes (see Figure 16).

Lessons learned

So far, the SaTu system has been used in one emergency exercise. The reference accident sequence described an initiating event of a primary leakage into the upper compartment. Without emergency core coolant injection, the accident progression was very rapid with significant containment over-pressurisation. It appeared that it was very difficult to introduce input data to the system during such a rapid sequence. At the time of the exercise, there was no pre-calculated sequence describing a primary leakage into the upper compartment, and after the exercise, it was discussed, that the pre-calculated sequences play an important role in such sequences, where the core uncovery takes place rather soon after the initiating event.

According to the probabilistic safety analysis results of Loviisa 1, much slower sequences than that described above contribute a major part to the total core damage frequency. Therefore in real accident situations, it could be assumed that the user would have much more time to go through the assumptions needed in SaTu.

SaTu has not been designed to be a nuclear power plant analyser (NPA). SaTu cannot replace on-site radiation measurements but these two information sources complete each other: real measurements tell the actual situation and SaTu estimates the potential situation during accident progression.

SaTu has been designed to be optimized in term of number of radionuclides information from user, time of calculation. However, it has to be noted that the users must be quite familiar with the system and its capabilities in order to work efficiently with the system - this is achieved by training. Pre-calculated sequences are also needed both in the training and in real accident situations with fast accident progression, where there is very little time to fill out the input data forms.

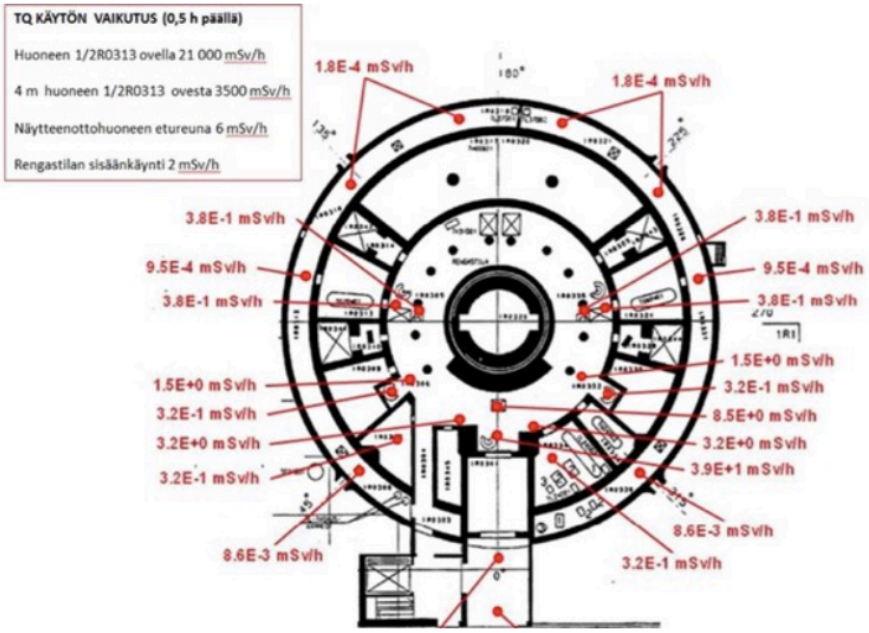


Figure 17. Example of predictive dose mapping obtained with SaTu software.

References

SaTu: Support System for Radiation Expert, T. Routamo, T. Eurajoki, P. Lundström, OECD/CSNI SAM Workshop on Operator Training and Instrumentation Capabilities Lyon, France, 12-14 March 2001 and discussion with T. Konio, Radiation Protection Manager of Loviisa, may 2016.

7.1.4 The specific case of ALARA approach for on-site responders after an radiological accident

In the 'late phase' after an accident, the work on-site aims at the dismantling of the damaged facility, including the management of the corresponding waste. The source is considered as secured and the radiological situation is *a priori* characterized. However, it could be a period of several years in this phase in which the source is stabilized without being totally secured and some aspects of the situation are not fully characterized (e.g. hot spots). Significant hazards can still occur.

In such a period, many workers are involved in the response on-site, more than during the normal operation of the facility. At Fukushima-Daiichi power plant, the number of workers raised from around 2000 (April 2011) to 7500 (March 2014). Some are regular workers from the plant, but most of them are outside workers (e.g. contractors). The conditions of work are unprecedented and difficult. The site has suffered damages and is contaminated. At the beginning of the phase, the on-site radiological situation is partially unknown and requires full characterization. Human error or an external aggression may lead back to an emergency. In such prevailing circumstances, the workers can still be considered as responders. With time, the better the situation is characterized, the more the management of workers can be consistent with the system applicable to occupational exposure. However, flexibility is still needed. The optimization process should be adapted to the prevailing circumstances.

In such situation, the classical factors of time, distance and shielding of the optimization process have to be questioned. First, the number of responders involved and the duration of their stay on-site should be maintained at levels considered necessary. Lower dose paths and trails can be delineate as well as low dose area for long stay. Decontamination procedures may be implemented. Because most of the workers do not know the facility and have no particular skill and competences in radiological protection, attention should be paid to their risk-awareness and training. The responders should be involved in their own protection. A coaching may be organised by the operating management in order to balance the lack of radiological protection culture.

In terms of dose restriction, the application of dose limits is not well appropriate and the application of a reference level is preferable. The reference level should be selected according to the circumstances and after consultation. It should not be more than 100 mSv at the beginning and should decrease to 20 mSv or lower in the recovery phase. It might still evolve during the phase. Continuous efforts should be developed to improve the working conditions in the optimization process.

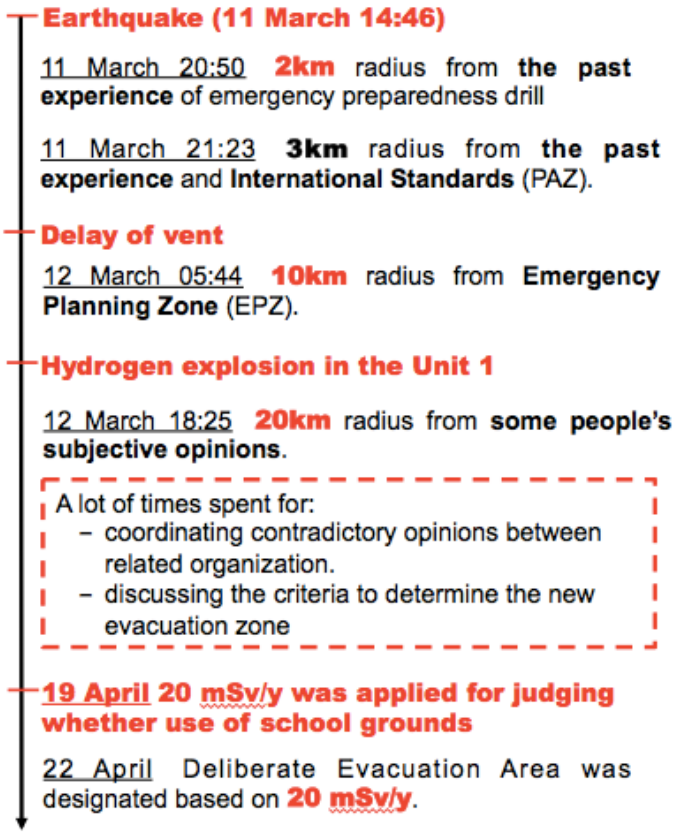
Reference

Responders on-site in the late phase of an accident- the ALARA approach, J-F Lecomte, presentation made at the occasion of EAN 17th Workshop, Lisbon, 2017.

7.2 Public exposures in emergency exposure situations

7.2.1 The difficulty in using dose criteria for public in emergency situations

ICRP recommend selecting a dose reference level in term of effective dose in a 20–100 mSv bands (acute or per year) for emergency exposure. The Fukushima accident is the first experience for considering these issues. However, before the Fukushima Daiichi Nuclear Power Plant accident, insights had been insufficient for implementing the update and the choice of reference level in post accident situation. To exemplify this statement, the following time-line for evacuation can be reported:



It can be seen that different rationale for evacuation has been used as the accident was on-going. Furthermore, they were contradictory opinions between authorities to evacuate an area (or not). Lot of time was spent in coordination and discussion and various considerations interfered in the decision: Fukushima Prefecture assumed that "changing the zones of evacuation will cause confusion among residents" (21 March). The same opinion was share by the mayor of Itate Village, not evacuated in March 2011 (as the accident occur), but evacuated later in April 2011.

The National Radiation Protection Authority was confronted with the choice of selecting a dose reference level in the 20-100 mSv band. The former dose criterion for evacuation was 50 mSv (based on ICRP Publication 63 and IAEA BSS 115) and it was considered by the Authority to be equivalent to 20 mSv/y. A "hourly dose rate reference level" was then inferred: Considering 20 mSv/y on 365 day

will make a 54,7 μSv/day, then using a protection factor of 0.4 indoor (16 hours/day) and no protection factor outside, it was calculated that the reference level *x* should be such as:

$$8x + 0{,}4 \times 16x = 54{,}7$$
$$\text{hence } x = 54.7 / 14.4 = 3.8 \text{ μSv/h}$$

It is recognized that this scheme has some issues: it does not take into account the dose conversion (from ambient to effective dose), it considers only external exposure, is not time dependent (physical decay and weathering) and do not considered differences between individuals and their behaviour. This reference level is still in force and is now very questioned and criticised for being too conservative.

Additional confusion emerged when the same reference level (20 mSv/y) was used by the Ministry of Education, Sport, Science and Technology (MEXT) for the resumption of schools (N.B. not located in the evacuated zone) (decision of 19 April 2011). Based on radioactivity measurements, MEXT considered that if the reference level was too low, many school cannot be reopened.

The Japanese public strongly protested that 20 mSv/y was too high, notably because the benchmark for ensuring the safety of children was the same as the one for evacuation. It was considered that the basis of decision was not clear and not scientifically grounded. Comparison with other standards such as the 1 mSv/y dose limit for public from planned exposure was also made.

Several confusions were caused by the selection and the use of the reference level and other numerical criteria during the Fukushima accident. The questions of the reasonableness of the dose criteria (reference level vs. operational quantities, comparison with past experience, standards and other protective actions), their appropriate update in a timely manner and the explanation of the rationale of the decision have been raised, but not answered.

Reference

Implementing optimization in post-accident situation: Some lessons from Fukushima, T. Shogo, Japan Atomic Energy Agency, presentation made at the occasion of EAN 17th Workshop, Lisbon, May 2017.

7.2.2 Management of contaminated food: application on the Irish dairy sector

In Ireland, the National Emergency Plan for Nuclear Accident (NEPNA) – gathering various government Departments and other public authorities – is in charge of providing advice on countermeasures and coordinating their implementation. One potential countermeasure is food control and agricultural protective measures.

Milk account for the second largest share of Ireland gross agriculture output, 85 % of the production is exported, the value of dairy export is around 3 billion € per year. Milk production is a grass-based system, hence marked with seasonality: 80 % of Irish dairy cows calve in the spring up to autumn. Milk production peaks (ratio 7 to 1) in May and June in Ireland. It is recognized that milk is particularly vulnerable to nuclear fallout and contamination.

A multi agency expert groups, under the auspices of NEPNA, was set up in 2008 with the objectives of producing an Irish Food Handbook to avoid/minimize damage to Irish economy (export) and develop reflex actions and key messages. Actions are focused on the early emergency phase. All food production sectors were considered and milk production in particular.

The reflections of the expert group were primarily guided by the 'Generic Handbook for Assisting in the Management of Contaminated Food Production in Europe Following a Radiological Emergency' (EURANOS Handbook, 2009). The EURANOS recommendations are generic and have to be *customized* for the specificities of Irish dairy sector to:

- Produce clean milk,
- Dispose of milk unfit for consumption,
- Provide advices to farmers, processors and distributors etc.

Many considerations were to be taken into account in the reflection: maximum contaminated level in milk, type and amount of radionuclides, time of transfer, time of year when accident occur etc.

An evaluation was performed to identify the most vulnerable period of the year. For each month:

- The lactation period (calving, early lactation, mid lactation, …),
- The milk production,
- The feeding system (housed, at grass by day, at grass all time, …),
- The availability of uncontaminated feed (likely vs. unlikely),
- And the availability of on farm storage (likely vs. unlikely)

were considered. April to July has been identified as the most vulnerable period because cows are grazing outdoor, the milk production is high and clean feed stock are at the lowest after the winter.

With these results, a *seasonal* table of actions, *specific* for the potentially at stake Irish dairy sector has been proposed. This is an example of shaping and tuning the protective actions to the vulnerable sector and period so to avoid over conservatism and linked side effect (economic consequences, etc.) The use of ammonium ferric hexacyanoferrate (AFCF), clean feed and decontamination of milk are considered. Within the PREPARE projects, the Food Handbook working group has been extended to farmers, food processors, food distributors etc. to discuss about the feasibility of these actions and especially their social acceptance.

At the time of the redaction, exercises are needed to validate the actions and test the channel of communication.

Reference

Management of Contaminated Food, Application to the Irish Dairy Sector, C. Organo, Irish Environmental Protection Agency, presentation made at the occasion of EAN 17th Workshop, Lisbon, May 2017.

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CONCLUSION

More than a quarter of a century after the publication of the European report on 'ALARA - from Theory towards Practice', this Guidebook is built on 25 years of practical implementation of ALARA in various exposure situations.

Starting from a general scheme of the various steps of an ALARA process, the Guidebook explores the particularities of ALARA implementation in planned, existing or emergency exposure situations based on real experiences. As judgments are needed on the interpretation of ALARA ('reasonably achievable') as well as how to 'take into account social and economic factors', whatever the situation, it is clear that the involvement of the relevant stakeholders is a key element to identify the necessary protective actions and to reach a "reasonable" level of radiological protection. Another important aspect of the ALARA process is to integrate - when applicable - the radiological risk in the frame of a holistic / integrated approach of risk management.

In order to implement the ALARA principle successfully, it is crucial to engender in everybody working with radiation protection 'ALARA-consciousness' - and this Guidebook can be considered as a tool to favour the dissemination of an ALARA Culture among all persons involved in the management of radiological protection.

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APPENDIXES

APPENDIX A CREATION OF A RADIOLOGICAL RISK MANAGEMENT SYSTEM - BASIC CONCEPTS

A.1 Radiation protection: from its scientific basis to regulations

The radiation protection regulations in force in most of the European Member States are fairly similar, since they generally comply with previously set international standards.

Indeed, research results on radiation risks are analysed, summarised and systematised by International Organizations like the *Radiation Effects Research Foundation* (RERF) in Japan, the *United Nations Scientific Committee on the Effects of Ionising Radiation* (UNSCEAR) and the *US National Academy of Science Committee on the Biological Effects of Ionizing Radiation* (NAS-BEIR). These international organizations inform the recommendations formulated by the *International Commission on Radiological Protection* (ICRP) and the *International Commission on Radiation Units and Measurements* (ICRU) and, for the USA only, the *National Council on Radiation Protection* (NCRP). These recommendations in turn are the basis of the international safety standards of the *European Atomic Energy Community* (EURATOM) and the *International Atomic Energy Agency* (IAEA), regional standards, and topical standards as shown in the flow chart of Figure A1. This figure represents the route from basic scientific studies to national radiation protection regulations and the interconnection between the different bodies involved in development and/or implementation of radiation protection systems

In Appendix B, a short description is given of the major organizations involved in developing the scientific basis of radiation risk; the bodies formulating the system of protection, drafting radiological protection standards, issuing recommendations and regulations guidance; and relevant professional societies, standardisation organizations and networks.

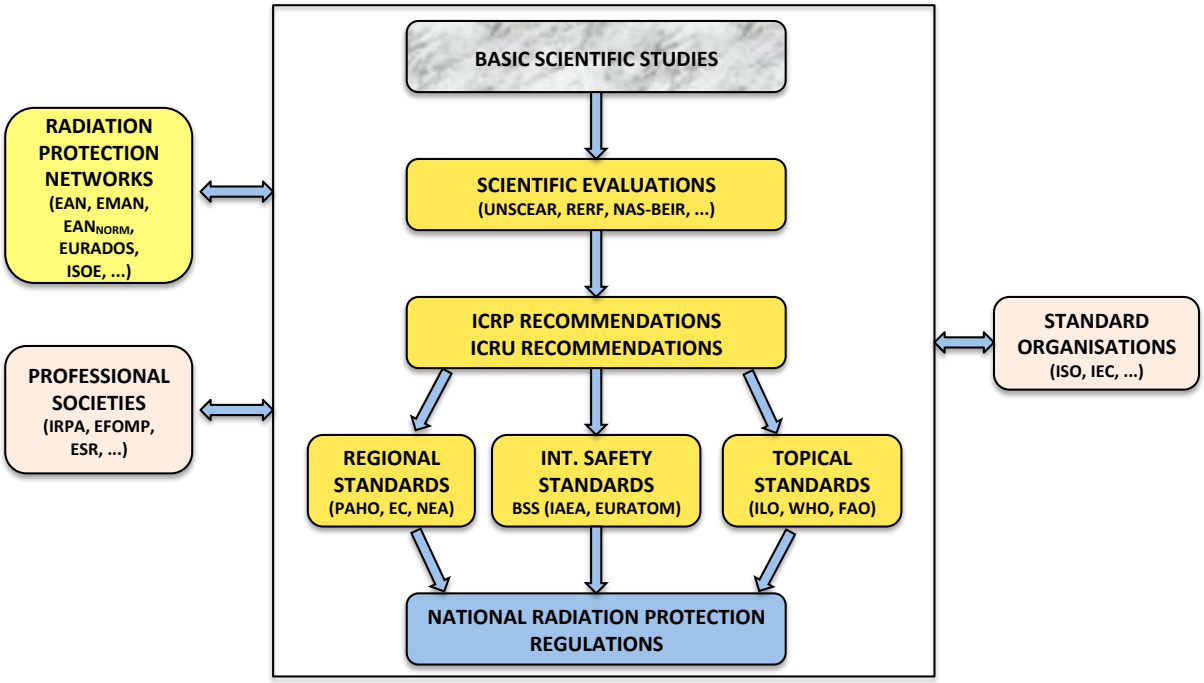

Figure A1. The organization of radiation protection at international level, from the scientific basis to the implementation of national regulations

A.2 The effects of ionising radiation on health

Ionising radiation was discovered and used for the first time at the end of the nineteenth century. Röntgen produced X-rays in 1895 and the following year Becquerel proved the existence of naturally-occurring radioactivity. The deleterious effects of radiation on users of X-rays and radium rapidly became apparent. These effects included severe skin problems and potentially fatal damage to haematopoietic organs such as bone marrow.

In the 1930's, the various effects of radiation were gradually determined (erythema, skin dermatitis, cataract, sterility, vomiting, death, etc.). Exposure thresholds, above which these so-called "deterministic effects" were certain to occur and below which no effects of this type were observed, were established for the various organs exposed.

As far back as the early 1930's, the ICRP proposed exposure limits for various organs (known as "tolerated doses" then "allowable doses") which were well below the thresholds at which deterministic effects occurred. This was considered a sure-fire way of preventing these effects from occurring at all.

Other effects on health started to become apparent in the 1920's in frequently-exposed individuals. In particular, an abnormally high incidence of leukaemia was observed in the pioneers of X-rays for medical purposes. Furthermore, laboratory experiments carried out on fruit flies in 1927 showed that genetic mutation was possible following exposure to high doses of radiation. These effects were the first signs that there could be other risks associated with ionising radiation, in addition to those already identified.

These health effects (fatal and non-fatal cancers, genetic effects) occur below the thresholds set for deterministic effects. They are known as stochastic (or probabilistic) effects since they occur at random in a given population. Within an exposed population, it is not possible to predict *a priori*, which individuals will develop a form of cancer that can be attributed to radiation. Furthermore, it is impossible to recognise *a posteriori* which cancers, of all those that have developed within an exposed population, can be attributed to radiation.

In summary, for the first 60 years after the discovery of ionising radiation, the purpose of radiological protection was that of avoiding deterministic effects from occupational exposures, and the principle aim of radiological protection was to keep exposures of individuals below the relevant thresholds. It was only with the 1977 Recommendations (Publication 26 (ICRP, 1977)) that the ICRP first quantified the risks of stochastic effects of radiation (Clarke and Valentin, 2009).

ICRP Publication 103 (ICRP, 2007), which proposed the current system of radiological protection, defined these type of effects in the following way.

- **Deterministic effect**s: Injury in populations of cells, characterised by a threshold dose and an increase in the severity of the reaction as the dose is increased further. Also termed tissue reaction. In some cases, deterministic effects are modifiable by post-irradiation procedures including biological response modifiers.
- **Stochastic effects**: Malignant disease and heritable effects for which the probability of an effect occurring, but not its severity, is regarded as a function of dose without threshold.

A.2.1 Deterministic effects (harmful tissue reactions) in population

When doses greater than a certain value occur there may be a substantial amount of cell killing, sufficient to result in detectable tissue reactions. For this reason the induction of tissue reactions is generally characterised by a threshold dose. This threshold dose is present because radiation damage (serious malfunction or death) to a critical number of cells in a given tissue needs to occur before injury is expressed in a clinically relevant form. Above the threshold dose the severity of the injury, including impairment of the capacity for tissue recovery, increases with dose. The incidence and severity of tissue and organ reactions vary with the dose received. These reactions may occur early or late after irradiation and are distinct from the stochastic effects in single cells, which are the induction of cancers from irradiated somatic cells, and genetic diseases in offspring following parental germ cell irradiation. In ICRP Publication 60 (ICRP, 1991) effects caused by injury in populations of cells were called deterministic, meaning 'causally determined by preceding events'. In the last ICRP Recommendations (ICRP, 2007) it is recognised that both early and late tissue reactions are not necessarily predetermined, and they can be modified after irradiation by the use of various biological response modifiers. For this reason ICRP considered it more accurate to refer to these effects as early or late tissue or organ reactions: "These effects, previously called 'deterministic effects', are now referred to as 'tissue reactions' because it is increasingly recognised that some of these effects are not determined solely at the time of irradiation but can be modified after radiation exposure" (see Publication 118 (ICRP, 2012)). However, the generic terms, deterministic and stochastic effects, have a firmly embedded use in ICRP system of protection and the use of a generic term (deterministic) and a directly descriptive term (tissue reactions) can be synonymous. Values of threshold doses for tissues reactions can be found in table A.3.4 in Annex A of ICRP Publication 103 (ICRP, 2007).

In Publication 118 (ICRP, 2012) ICRP stated different threshold doses for tissue reactions compared with those in Publication 103 (ICRP, 2007). In the case of radiation-induced eye cataracts the threshold dose is now considered to be approximately 0.5 Gy for both acute and fractionated exposures, in line with various recent epidemiological studies.

A.2.2 Non cancer diseases

Another important change from ICRP 118 relates to the fact that circulatory disease was recognised as an important late effect of radiation exposure, both for mortality and morbidity. An approximate threshold dose of 0.5 Gy has been proposed for acute and fractionated/protracted exposures on the basis that this might lead to an incidence of the order of 1% of circulatory disease in exposed individuals, although the estimation of risk at this level of dose is particularly uncertain.

Evidence that the frequency of non-cancer diseases is increased in irradiated populations mainly derives from the A-bomb Life Span Study (LSS), and the most recent mortality analyses (Osaka et al., 2012; Preston et al., 2003) have shown statistically significant increases for heart disease, stroke, digestive disorders and respiratory disease. There is no direct evidence of radiation effects on non-cancer mortality for doses less than about 0.5 Sv. Additional data evidencing these effects, albeit at high doses, come from studies of cancer patients receiving radiotherapy doses of several tens of Gy (e.g., Hancock et al. 1993; Aleman et al., 2003; Early Breast Cancer Trialists Collaborative Group, 2000). The situation at lower doses is less clear. This is the reason why the ICRP, while recognising the potential importance of these observations on non-cancer diseases, "...judges that the data available do not allow for their inclusion in the estimation of detriment following radiation doses in the range up to around 100 mSv" (ICRP 2007). This agrees with the conclusion of UNSCEAR Report 2008 (UNSCEAR, 2010), which found little evidence of any excess risk below 0.5 Sv. In a successive ICRP publication this is confirmed stating that "... after acute or accumulated doses of > 0.5 Gy, the risk of tissue reactions (deterministic effects) becomes increasingly important, particularly for the lens of the eye and the circulatory system, at very long times after radiation exposure." (ICRP, 2012).

A.2.3 Stochastic effects (cancer and hereditary effects) in population

The term stochastic effect was introduced (ICRP, 1977) in order to describe the single-cell effect caused by a random process of deposition of energy by ionising radiation (see Publication 41 (ICRP, 1984)). These effects, resulting from damage in a single cell, may occur even at very low doses since it is possible that sufficient energy may be deposited into a critical volume within a cell to result in cellular changes or cell death. The killing of one or a small number of cells will, in most cases, have no consequences in tissues. On the other hand modifications in single cells, such as genetic changes or transformations leading ultimately to malignancy, may have serious consequences. Such stochastic events may occur with a finite probability even at very low doses, so there will be no threshold dose unless all such events can be repaired up to some level of dose. With the increase in dose the frequency of such events increases, but in the absence of other modifying factors, the severity of the resultant effects is not expected to increase, in contrast with the case of tissue reactions. The ICRP nominal risk coefficients for cancer and heritable effects published in the ICRP Recommendation 103 (ICRP, 2007) are presented in Table A1 together with the previous values published in ICRP Recommendation 60 (ICRP,1991).

Table A1. Detriment-adjusted nominal risk coefficients (10^{-2} Sv^{-1}) for stochastic effects after exposure to radiation at low dose rate

Exposed Population	Cancer		Heritable effects		Total	
	ICRP 60	ICRP 103	ICRP 60	ICRP 103	ICRP 60	ICRP 103
Whole	6.0	5.5	1.3	0.2	7.3	5.7
Adult	4.8	4.1	0.8	0.1	5.6	4.2

A.2.4 Prenatal Effects

In the last decades of the past century a growing awareness of the risks connected with prenatal exposure to ionising radiation arose in the scientific community. This was related to the strong epidemiological evidence about mental retardation (Schull, 1996), emerging from the re-analyses of the Hiroshima and Nagasaki data in the 1980's (RERF, 1987), and to the acknowledgement, after decades of scepticism, by international organizations and bodies (ICRP, 1991; ICRP, 2003) of the Stewart data about childhood cancer (Stewart et al., 1956). Indeed, the large case-control studies of *in-utero* medical irradiation - carried out by Stewart and co-workers - provided evidence of increased childhood cancer of all types.

The main results are reported in the last ICRP Recommendations (ICRP, 2007) and are here summarised:

- For dose < 100 mGy:
  - lethal effects will be very infrequent;
  - no risk of malformation induction is expected (well below 100 mGy);
  - any effects on intelligence test scores (IQ) following *in-utero* doses would be of no practical significance;
  - the assumption of a life-time cancer risk from *in-utero* exposure similar to risk from irradiation in early childhood (about three times that of the population) is considered prudent; the ICRP recognises particular uncertainties on the risk of solid cancers.

- For dose > 100 mGy:
  - susceptibility to lethal effects in the pre-implantation period of embryonic developments;
  - induction of malformations with maximum sensitivity during the period of major organogenesis (4 - 14 weeks post conception) with a dose threshold of around 100 mGy;
  - severe mental retardation is induced following irradiation in the most sensitive prenatal period (8-15 weeks post conception) with a dose threshold of at least 300 mGy.

The same Recommendations report that "... data on IQ losses estimated at around 25 points per Gy are more difficult to interpret and the possibility of a non-threshold dose response cannot be excluded. However, even in the absence of a true dose threshold, any effects on IQ following *in-utero* doses under 100 mGy would be of no practical significance".

This acquired knowledge and awareness of the risks of prenatal exposure to ionising radiation had a subsequent effect on the regulations in the field of both occupational and medical exposure (EC, 1996; EC, 1997; IAEA, 2011).

A.3 Exposures to ionising radiation

ICRP Publication 103 (ICRP, 2007) defines three types of exposure situations, *planned*, *existing* and *emergency exposure situations* - where the implementation of the system of protection should be made - and three types of categories of exposure, *occupational exposure, public exposure and medical exposure of patients.* This paragraph will present these concepts summarising the ICRP 103 definitions and explanations.

A.3.1 Exposure situations

The three types of exposure situations are defined by ICRP in the following way:

Planned exposure situations: Everyday situations involving the planned operation of sources including decommissioning, disposal of radioactive waste and rehabilitation of the previously occupied land. Practices in operation are planned exposure situation.

Existing exposure situations: A situation that already exists when a decision on control has to be taken, including natural background radiation and residues from past practices that were operated outside the Commission's recommendations.

Emergency exposure situations: An unexpected situation that occurs during the operation of a practice, requiring urgent action. Emergency exposure situations may arise from practices.

A.3.1.1 Planned exposure situations

Planned exposure situations occur when the deliberate introduction and operation of sources are involved. For this reason, radiological protection can be planned in advance, before exposures occur, and the magnitude and extent of the exposures can be reasonably predicted. Planned exposure situations may give rise to both exposures that are anticipated to occur (*normal exposures*) and exposures that are not anticipated to occur (*potential exposures*). The principles of protection for planned situations also apply to planned work in connection with existing and emergency exposure situations, once the emergency has been brought under control.

All categories of exposure (see Section A.3.2) can occur in planned exposure situations, i.e., *occupational exposure*, *public exposure* and *medical exposure of patients*, including their comforters and carers.

A.3.1.2 Existing exposure situations

Existing exposure situations are exposure situations that already exist when a decision on control has to be taken, including prolonged exposure situations after emergencies. Many types of existing exposure situations may cause exposures high enough to warrant radiological protective actions, or at least their consideration. Radon in dwellings or the workplace, and naturally occurring radioactive material (NORM) are well-known examples. Radiological protection decisions may also be needed in existing man-made exposure situations such as residues in the environment due to radiological emissions from operations that were not conducted within the system of protection, or contaminated land resulting from an accident or a radiological event. Existing exposure situations can be complex in

that they may involve several exposure pathways and they generally give rise to wide distributions of annual individual doses, ranging from the very low to, in rare cases, several tens of millisieverts. Such situations often involve dwellings, for example in the case of radon, and in many cases the behaviour of the exposed individuals determines the level of exposure.

A.3.1.3 Emergency exposure situations

Emergency exposure situations are situations that may occur during the operation of a planned situation, or from a malicious act, or from any other unexpected situation, and require urgent action in order to avoid or reduce undesirable consequences.

Actual emergency exposure situations are inherently unpredictable, the exact nature of necessary protection measures cannot be known in advance, but must flexibly evolve to meet actual circumstances.

ICRP emphasises the importance of justifying and optimising protection strategies for application in emergency exposure situations, the optimization process being guided by reference levels. The possibility of multiple, independent, simultaneous, and time-varying exposure pathways makes it important to focus on the overall exposures that may occur from all pathways when developing and implementing protective measures. The dose that would result when a protection strategy is implemented is called the *residual dose*. In addition, each protective measure will avert a certain amount of exposure. This is referred to as *averted dose*. ICRP recommends focusing on optimization with respect to the overall strategy, rather than the individual measures. However, the levels of averted dose recommended in Publication 63 (ICRP, 1992) for optimization of protection in terms of individual protective measures may still be useful as inputs to the development of the overall response.

A.3.2 Categories of exposure

There are three categories of exposures: occupational exposures, public exposures and medical exposures of patients.

A.3.2.1 Occupational exposure

Occupational exposure is defined by ICRP as all radiation exposure of workers incurred as a result of their work and its use is limited to radiation exposures incurred at work as a result of situations that can reasonably be regarded as being the responsibility of the operating management. Excluded exposures and exposures from exempt practices or exempt sources generally do not need to be accounted for in occupational protection.

The employer has the main responsibility for the protection of workers. However, the licensee responsible for the source - if not identical to the employer- also has a responsibility for the radiological protection of workers. If workers are engaged in work that involves, or could involve, a source that is not under the control of their employer, the licensee and the employer should co-operate by the exchange of information and otherwise as necessary to facilitate proper radiological protection at the workplace.

A.3.2.2 Public exposure

Public exposure encompasses all exposures of the public other than occupational exposures and medical exposures of patients.

Members of the public are exposed to a range of radiation sources, with natural sources being the largest proportion of total dose. However, this provides no justification for reducing the attention paid to smaller, but more readily controllable, exposures to man-made sources.

Exposures of the embryo and foetus of pregnant workers are considered and regulated as public exposures.

A.3.2.3 Medical exposure of patients

Radiation exposures of patients occur in diagnostic, interventional, and therapeutic procedures.

There are several features of radiological practices in medicine that require an approach that differs from the radiological protection in other planned exposure situations. The exposure is intentional and for the direct benefit of the patient. Particularly in radiotherapy, the biological effects of high-dose radiation, e.g., cell killing, are used for the benefit of the patient to treat cancer and other diseases.

A.4 Three principles for responsible management of radiological risks

Internationally, the system of radiation protection is based on the three principles of *justification*, *optimization* and *dose limitation*. These principles adopted for the first time in Publication 26 (ICRP, 1977) were confirmed in the subsequent revised ICRP Recommendations, that is first in ICRP Publication 60 (ICRP, 1991) and afterwards in Publication 103 because ICRP "... continues to regard these principles as fundamental for the system of protection" (ICRP, 2007). Indeed, having accepted that there is a possible detriment to health regardless of the level of dose received, the exposure limit previously used to prevent the onset of deterministic effects is no longer sufficient for managing all of the risks associated with radiation exposure. Therefore radiological risk management is based on the three cited principles. ICRP Publication 103 defines in its glossary the three principles as follows:

- **Justification**: the process of determining whether either (1) a planned activity involving radiation is, overall, beneficial, i.e. whether the benefits to individuals and to society from introducing or continuing the activity outweigh the harm (including radiation detriment) resulting from the activity; or (2) a proposed remedial action in an emergency or existing exposure situation is likely, overall, to be beneficial, i.e. whether the benefits to individuals and to society (including the reduction in radiation detriment) from introducing or continuing the remedial action outweighs its cost and any harm or damage it causes.
- **Optimization of protection (and safety)**: the process of determining what level of protection and safety makes exposures, and the probability and magnitude of potential exposures, as low as reasonably achievable, economic and societal factors being taken into account.
- **Dose limitation**: the value of the effective dose or the equivalent dose to individuals from planned exposure situations that shall not be exceeded.

However, in the text of ICRP Publication 103 a more simple and straightforward description of the principles can be found.

- **Justification**: any decision that alters the radiation protection exposure situation should do more good than harm.
- **Optimization of protection**: the likelihood of incurring exposures, the number of people exposed, and the magnitude of their individual doses should all be kept as low as reasonably achievable, taking into account economical and societal factors.
- **Application of dose limits**: the initial dose to any individual from regulated sources in planned exposure situations other than medical exposure of patients should not exceed the appropriate limits recommended by the Commission.

The first two principles are *source-related* and apply in all exposure situations, whereas the last one is *individual-related* and only applies in *planned exposure situations*.

A.4.1 Justification

The justification principle is applied differently, depending on whether or not the source can be directly controlled. When the radiological protection is planned in advance, and therefore it is possible to act directly on the source, as for new activities involving radiation exposures, the justification principle requires that no new activity is introduced "... unless it produces sufficient net benefit to the exposed individuals or to society to offset the radiation detriment it causes". Where, however, it is not possible to act on the source but only to modify the exposure, "...the principle of justification is applied in making the decision as to whether to take action to avert further exposure" considering if it does more good than harm. This applies, for example, in *existing exposure situations* and *emergency exposure situations*.

Excluding medical applications, the responsibility for judging the justification usually falls on governments or national authorities, however, the role of users, other organizations or person outside of government could be important in providing necessary information. In certain cases, e.g. for big sources, a process of public consultation could be essential. Instead, for medical exposure of patients justification is based more often on professional competences. In this case risk-benefit analysis should not only be applied to the patient, but to the staff and other involved individuals, too.
Some examples of justified or unjustified initiatives can be:

- in many countries it is justified to use nuclear power plant for producing energy, or to reduce the radon concentration in an indoor environment if the relevant doses are considered too high;
- it is unjustified to use X-ray images in shoe shops to ensure that shoes fit correctly .- a common custom at the beginning of the twentieth century - or to expose patients to unnecessary X-ray or CT examinations.

Moreover, ICRP states that "... certain exposures should be deemed to be unjustified without further analysis, unless there are exceptional circumstances" and these include:

- the deliberate addition of radioactive substances or the activation of food, beverages, cosmetics, toys, and personal jewellery and adornments;

- radiological examinations for occupational, health insurance or legal purposes if they do not provide useful clinical information or are not aimed at support of important criminal investigation;
- medical screening of asymptomatic population groups, if the risk-benefit analysis is not positive for the individual or the population as a whole.

A.4.2 Optimization of protection

The principle of optimization of radiation protection is central to the system of protection and applies to all type of exposures: *planned*, *existing* and *emergency exposure situations* (see Section A.5). It is defined by ICRP "...as the source-related process to keep the likelihood of incurring exposures ... the number of people exposed, and the magnitude of individual doses *as low as reasonably achievable*, taking economic and societal factors into account".

Optimising radiation protection means that the level of protection should be the best under the prevailing circumstances, maximising the margin of benefit over harm. Indeed, it is not simply the minimisation of dose and the best option is not necessarily the one with the lowest dose.

It is a forward-looking iterative process aimed at preventing or reducing future exposures. It is a frame of mind, always questioning whether the best has been done in the prevailing circumstances, and whether all that is reasonable has been done to reduce doses. ICRP maintains (ICRP, 2007) that "..the process of optimization over the past decades has resulted in substantial reductions of occupational and public exposures".

Lastly, it may be useful to re-cap the history of the concept of optimization of radiation protection in the ICRP Recommendations.

At the beginning, assuming that there was a risk regardless of dose level, the ICRP advocated a radiological protection philosophy based on systematic identification of a *minimum risk*, or even *zero risk*, expressed as a recommendation to "reduce doses to the lowest possible level" (ICRP, 1951). However, the radiological protection philosophy developed through the ICRP recommendations has gradually evolved to better integrate the reduction of radiological risks into the economic and social context. The initial wording of the recommendation was therefore changed in 1959 (ICRP, 1959) to "as low as practicable", then in 1966 (ICRP, 1966) to "as low as is readily achievable, economic and social considerations being taken into account". In 1973 (ICRP, 1973), the wording "as low as reasonably achievable in view of the economic and social factors" was adopted. In the radiological protection world it is known as the *ALARA principle*. In 1991 in its 1990 Recommendations (ICRP, 1991), the ICRP once again insisted on the importance of the ALARA principle. In the latest Recommendations (ICRP, 2007), however, the acronym ALARA is not present, but it is largely substituted by the expression "optimization of radiation protection", which ICRP in its Publication 42 (ICRP, 1985) maintains are synonymous and interchangeable.

Table A2. Evolution of the ALARA wording

To **reduce** exposures	to the lowest	possible level		(ICRP, 1951)
To **keep** the exposure of large population	as low as	practicable		ICRP Publ. 1 (ICRP, 1959)
All doses (should) be kept	as low as	is readily achievable	**economic** and **social consideration** being taken into account	ICRP Publ. 9 (ICRP, 1966)
All doses (should) be kept	as low as	reasonably achievable	economic and social consideration being taken into account	ICRP Publ. 22 (ICRP, 1973)
All exposures shall be kept	as low as	reasonably achievable	economic and social **factors** being taken into account	ICRP Publ. 26 (ICRP, 1977)
The magnitude of individual doses, the number of people exposed and the likelihood of incurring uncertain exposures shall all be kept	as low as	reasonably achievable	economic and social factors being taken into account	ICRP Publ. 60 (ICRP, 1991)
The likelihood of incurring exposures, the number of people exposed, and the magnitude of individual doses should all be kept	as low as	reasonably achievable	economic and **societal** factors being taken into account	ICRP Publ. 103 (ICRP, 2007)

A.4.3 Limitation of individual doses

Regulatory dose limits are determined by the regulatory authority, taking account of international recommendations, and apply to workers or members of the public in *planned exposure situations*, as already cited above, but not for medical exposure of patients[9]. They apply for occupational and public exposure to the sum of the exposures from all regulated sources. The limits on effective dose apply to

[9] In the medical field, indeed, limiting individual doses is not appropriate for patients, but the justification and optimization principles still apply.

the sum of doses due to external exposures and committed doses from internal exposures due to intake of radionuclides.

Whereas the concept of dose limitation introduces the notion of a threshold limit in the case of tissue reaction effects, with stochastic effects the limit is based on considerations concerning the acceptability of the residual risk. Complying with the regulatory dose limit is no longer a guarantee that there will be no effect on health. The risk associated to doses below the limits can be considered as "tolerable". In this case, there is a need to apply optimization of radiation protection to reach an "acceptable" level of risk, given the economic and societal factors.

A.5 Dose constraints and reference levels

The concepts of dose constraints and reference levels are used in conjunction with the optimization of protection to restrict individual dose. ICRP Publication 103 (ICRP, 2007) defines these two concepts in the following way:

Dose constraint: A prospective and source-related restriction on the individual dose from a source, which provides a basic level of protection for the most highly exposed individuals from a source, and serves as an upper bound on the dose in optimization of protection for that source. For occupational exposures, the dose constraint is a value of individual dose used to limit the range of options considered in the process of optimization. For public exposure, the dose constraint is an upper bound on the annual doses that members of the public should receive from the planned operation of any controlled source.

Reference level: In emergency or existing controllable exposure situations, this represents the level of dose or risk, above which it is judged to be inappropriate to plan to allow exposures to occur, and below which optimization of protection should be implemented. The chosen value for a reference level will depend upon the prevailing circumstances of the exposure under consideration.

In the same way as dose limits are not the boundary between *safe* and *unsafe* exposures, the same can be said for dose constraints and reference levels.

ICRP Publication 103 illustrates the differences between the use of individual dose limits in planned situations and constraints or reference levels for protection from a source in all situations, with a figure similar to that shown in Figure A2.

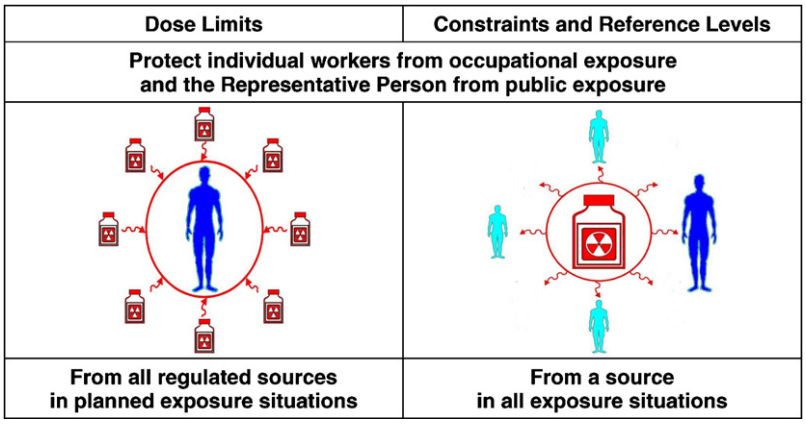

Figure A2. Dose limits contrasted with dose constraints and reference levels for protecting workers and members of the public (from ICRP Publication 103 (ICRP, 2007))

A.5.1 Dose constraints

Dose constraints are applied to planned exposure situations (except for medical exposure of patients). This means that the individual doses can be reduced at the planning stage and the doses assessed in advance, so that dose constraints should not be exceeded.

Dose constraints are not regulatory limits and, by the definition itself, are always lower than dose limits. Above the dose constraint it is unlikely that protection is optimised for a given source of exposure and, in any case, optimization of protection is required for all exposures, even below the dose constraint. For potential exposures, the corresponding source-related restriction is called a risk constraint.

Similarly to dose limits, dose constraints are not recommended for individual patients having medical procedures, because they may reduce the effectiveness of the patient's diagnosis or treatment, thereby doing more harm than good. Therefore, as regards medical procedures the emphasis is on the justification and optimization of protection and, for diagnostic procedures, the use of "diagnostic reference levels"; the latter being used in medical diagnosis to indicate whether, in routine conditions, the levels of patient dose or administered activity from a specified imaging procedure are unusually high or low for that procedure.

A.5.2 Reference levels

For emergency and existing exposure situations, the source-related restriction is the reference level. The choice of a reference level depends upon the prevailing circumstances of the exposure situation under consideration. All exposures above or below the reference level should be subject to optimization of protection, and particular attention should be given to exposures above the reference level.

Reference levels for existing exposure situations

ICRP recommends that reference levels, set in terms of individual dose, should be used in conjunction with the implementation of the optimization process for exposures in existing exposure situations. The objective is to implement optimised protection strategies, or a progressive range of such strategies,

which will reduce individual doses to below the reference level. However, exposures below the reference level should not be ignored; these exposure circumstances should also be assessed to ascertain whether protection is optimised, or whether further protective measures are needed. An endpoint for the optimization process must not be fixed a priori and the optimised level of protection will depend on the situation. It is the responsibility of regulatory authorities to decide on the legal status of the reference level, which is implemented to control a given situation. Retrospectively, when protective actions have been implemented, reference levels may also be used as benchmarks for assessing the effectiveness of the protection strategies. The use of reference levels in an existing situation is illustrated in Figure A3, which shows the evolution of the distribution of individual doses with time as a result of the optimization process.

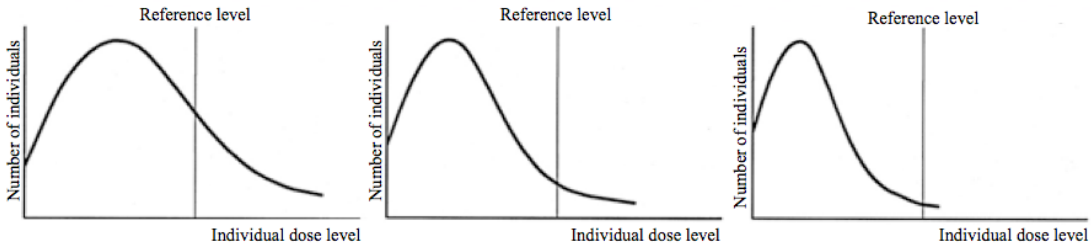

Figure A3. The use of a reference level in an existing exposure situation and the evolution of the distribution of individual doses with time as a result of the optimization process

Reference levels for existing exposure situations should be set typically in the 1 mSv to 20 mSv band of *projected dose*; that is the dose that would be expected to be incurred if no protective measure(s) were to be taken (see Table A3).

The individuals concerned should receive general information on the exposure situation and the means of reducing their doses. In situations where individual life-styles are key drivers of the exposures, individual monitoring or assessment as well as education and training may be important requirements. Living on contaminated land after a nuclear accident or a radiological event is a typical situation of that sort.

The main factors to be considered for setting the reference levels for existing exposure situations are the feasibility of controlling the situation, and the past experience with the management of similar situations. In most existing exposure situations, there is a desire from the exposed individual, as well as from the authorities, to reduce exposures to levels that are close to or similar to situations considered as *normal*. This applies particularly in situations of exposures from material resulting from human actions, e.g., NORM residues and contamination from accidents.

Reference levels for emergency situations

In planning for emergency situations, reference levels should be applied in the process of optimization. Reference levels for the highest planned residual doses from a radiological emergency are typically in the 20 mSv to 100 mSv band of projected dose as presented in Table A3 taken from ICRP (ICRP, 2007).

Table A3. Framework for source-related dose constraints and reference levels with examples of constraints for workers and the public from single dominant sources for all exposure situations that can be controlled (ICRP, 2007)

Bands of constraints and reference levels [a] (mSv)	Characteristics of the exposure situation	Radiological protection requirements	Examples
Greater than 20 to 100 [b, c]	Individuals exposed by sources that are not controllable, or where actions to reduce doses would be disproportionately disruptive. Exposures are usually controlled by action on the exposure pathways.	Consideration should be given to reducing doses. Increasing efforts should be made to reduce doses as they approach 100 mSv. Individuals should receive information on radiation risk and on the actions to reduce doses. Assessment of individual doses should be undertaken.	Reference level set for the highest planned residual dose from a radiological emergency.
Greater than 1 to 20	Individuals will usually receive benefit from the exposure situation but not necessarily from the exposure itself. Exposures may be controlled at source or, alternatively, by action in the exposure pathways.	Where possible, general information should be made available to enable individuals to reduce their doses. For planned situations, individual assessment of exposure and training should take place.	Constraints set for occupational exposure in planned situations. Constraints set for comforters and carers of patients treated with radiopharmaceuticals. Reference level for the highest planned residual dose from radon in dwellings.
1 or less	Individuals are exposed to a source that gives them little or no individual benefit but benefits to society in general. Exposures are usually controlled by action taken directly on the source for which radiological protection requirements can be planned in advance.	General information on the level of exposure should be made available. Periodic checks should be made on the exposure pathways as to the level of exposure.	Constraints set for public exposure in planned situations.

[a] Acute or annual dose.
[b] In exceptional situations, informed volunteer workers may receive doses above this band to save lives, prevent severe radiation-induced health effects, or prevent the development of catastrophic conditions.
[c] Situations in which the dose threshold for deterministic effects in relevant organs or tissues could be exceeded should always require action.

References

Aleman BM, van den Belt-Dusebout AW, Klokman WJ, et al, 2003. Long-term cause-specific mortality of patients treated for Hodgkin's disease. J. Clin. Oncol. 21, 3431–3439.

Clarke R.H., Valentin J. (2009). The History of ICRP and the Evolution of its Policies. Ann. ICRP 2009; 39(1):75-110.

Early Breast Cancer Trialists' Collaborative Group, 2000. Favourable and unfavourable effects on longterm survival of radiotherapy for early breast cancer: an overview of the randomised trials. Lancet 355, 1757–1770.

EC, 1996. Council Directive 96/29/Euratom of 13 May 1996, laying down basic safety standards for the protection of health of workers and the general public against the danger arising from ionizing radiation. Official Journal of the European Communities no L 159, 29.6.1996. Luxembourg, 1996.

EC, 1997. Council Directive 97/43/Euratom of 13 June 1997 on health protection of individuals against the dangers of ionising radiation in relation to medical exposures and repealing directive 84/466/Euratom. Official Journal of the European Communities no L 180, 9.7.1997. Luxembourg, 1997.

Hancock SL, Tucker MA and Hoppe RT, 1993. Factors affecting late mortality from heart disease after treatment of Hodgkin's disease. J. Am. Med. Assoc. 270, 1949–55.

IAEA, 2011. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. Interim Edition. General Safety Requirements Part 3. No. GSR Part 3 (Interim).

ICRP, 1951. International Commission on Radiological Protection. Recommendations of the International Commission on Radiological Protection, British Journal of Radiology1951; 24, 46-53.

ICRP, 1959. Publication 1. Recommendations of the International Commission on Radiological Protection. Superseded by ICRP Publication 103.

ICRP, 1966. Publication 9. Recommendations of the ICRP. Superseded by ICRP Publication 103.

ICRP, 1973. Publication 22. Implications of Commission Recommendations that Doses be Kept as Low as Readily Achievable. Pergamon Press

ICRP, 1977. Publication 26. Recommendations of the ICRP. Ann. ICRP 1977; 1 (3). Superseded by ICRP Publication 103.

ICRP, 1984. Publication 41. Non stochastic effects of Ionizing Radiation. ICRP Publication 41. Ann. ICRP 1984; 14 (3).

ICRP, 1985. Publication 42. A Compilation of the Major Concepts and Quantities in Use by ICRP. Ann. ICRP 1985; 14 (4). Superseded by ICRP Publication 103.

ICRP, 1991. International Commission on Radiological Protection. 1990 Recommendations of ICRP. ICRP Publication 60. Ann. ICRP 1991; 21 (1-3).

ICRP, 1992. Publication 63. Principles for Intervention for Protection of the Public in a Radiological Emergency. Ann. ICRP 1992; 22 (4).

ICRP, 2003. International Commission on Radiological Protection. Biological Effects after Prenatal Irradiation (Embryo and Fetus). ICRP Publication 90. Annals of the ICRP 2003; 33 (1-2).

ICRP, 2007. International Commission on Radiological Protection. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Annals of the ICRP 2007; 37 (2-4).

ICRP, 2012. ICRP Statement on Tissue Reactions and Early and Late Effects of Radiation in Normal Tissues and Organs – Threshold Doses for Tissue Reactions in a Radiation Protection Context. ICRP Publication 118. Ann. ICRP 41(1/2).

Ozasa, K., Shimizu, Y., Suyama, A., Kasagi, F., Soda, M., Grant, E. J., Sakata, R., Sugiyama, H. and Kodama, K. (2012). Studies of the Mortality of Atomic Bomb Survivors, Report 14, 1950–2003: An Overview of Cancer and Noncancer Diseases. Radiat. Res. 177, 229–243 (2012)

Preston DL, Shimizu Y, Pierce DA, Suyama A, Mabuchi K (2003). Studies of mortality of atomic bomb survivors. Report 13: Solid cancer and noncancer disease mortality: 1950-1997. Radiat Res;160(4):381-407.

RERF, 1987. US-Japan Reassessment of Atomic Bomb Radiation Dosimetry in Hiroshima and Nagasaki: Final Report. Roesch WC (ed). Hiroshima: Radiation Effects Research Foundation, 1987. (https://www.rerf.or.jp/)

Schull WJ (1996). Effects of atomic radiation. A half-century of studies from Hiroshima and Nagasaki. New York: Wiley-Liss, 1996.

Stewart AM, Webb J, Giles D, Hewitt D (1956). Preliminary communication: malignant disease in childhood and diagnostic irradiation in utero. Lancet 1956; 2: 447-448.

UNSCEAR, 2010. United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR 2008 REPORT Sources and Effects of Ionizing Radiation., Vol. I, SOURCES. Report to the General Assembly Scientific Annexes A and B. United Nations, New York, 2010. (http://www.unscear.org/unscear/en/publications.html).

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APPENDIX B MAJOR ORGANIZATIONS INVOLVED IN THE DEVELOPMENT OF THE RADIATION PROTECTION SYSTEM AND ITS IMPLEMENTATION

B.1 The major organizations involved in developing the scientific basis of the radiation risk

B.1.1 United Nations Scientific Committee on the Effects of Ionising Radiation (UNSCEAR)

UNSCEAR[10] assesses the levels of radiation to which the population of the world is or may be exposed due to natural or artificial sources and analyses the consequences for human health of the doses received. It was established by the *General Assembly* of the *United Nations* in 1955, in response to widespread concerns about the effects of radiation on human health and the environment. Its mandate in the United Nations system is to assess and report levels and effects of exposure to ionizing radiation. Governments and organizations throughout the world rely on the Committee's estimates as the scientific basis for evaluating radiation risk and for establishing protective measures. Over the decades, UNSCEAR has evolved to become the world authority on global levels and effects of ionizing radiation. The reports it publishes reflect the latest scientific findings.

The latest general[11] UNSCEAR Publication is the 2008 Report: *"Sources and effects of ionizing radiation"*, (UNSCEAR, 2010) which comprises the main text of the 2008 report to the General Assembly and 5 scientific annexes published in two volumes in 2010 and 2011 (UNSCEAR, 2010; UNSCEAR 2011):

- Annex A - Medical radiation exposures
- Annex B - Exposures of the public and workers from various sources of radiation
- Annex C - Radiation exposures in accidents
- Annex D - Health effects due to radiation from the Chernobyl accident
- Annex E - Effects of ionizing radiation on non-human biota.

B.1.2 US National Academy of Sciences Committee on the Biological Effects of Ionizing Radiation (NAS-BEIR)

NAS[12] is a private, non-profit society of distinguished scholars engaged in scientific and engineering research, dedicated to the furtherance of science and technology and to their use for the general welfare of the population. It was established by an Act of Congress that was signed by President Abraham Lincoln on March 3, 1863, which calls upon the NAS to "investigate, examine, experiment, and report upon any subject of science or art" whenever called upon to do so by any department of the government.

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10 http://www.unscear.org/

11 The most recent publication is the 2013 Report: "Sources, effects and risks of ionizing radiation", in two volumes. Volume I comprises the main text of the Report to the General Assembly and the Annex A - Levels and effects of radiation exposure due to the nuclear accident after the 2011 great east-Japan earthquake and tsunami, and Volume II: Annex B - Effects of radiation exposure of children.

12 http://nas.nasonline.org/

Since 1863, the nation's leaders have turned to these non-profit organizations for advice on the scientific and technological issues that frequently pervade policy decisions. Most of the institution's science policy and technical work is conducted by its operating arm, the *National Research Council* (NRC), which was created expressly for this purpose and which provides a public service by working outside the framework of government to ensure independent advice on matters of science, technology, and medicine.

A Committee of the National Research Council has an important role in building the scientific basis of radiation protection, this is the *Committee on the Biological Effects of Ionizing Radiation* (BEIR Committee), which regularly drafts a series of Reports informing the US government on the health effects of ionizing radiation. These reports, known as *BEIR Reports,* are published by the National Academy of Sciences.

The latest published Report, BEIR VII "Health Risks from Exposure to Low Levels of Ionizing Radiation, Phase 2" (BEIR VII, 2006) is the seventh in a series of titles that addresses the effects of exposure to low levels of low LET (Linear Energy Transfer) ionizing radiation and human health, developing comprehensive risk estimates for cancer and other health effects.

B.1.3 Radiation Effects Research Foundation (RERF)

RERF[13] is a bi-national Japan-USA scientific organization dedicated to studying the health effects of atomic bomb radiation for peaceful purposes, with a view to contributing to the health and welfare of the atomic-bomb survivors and to the enhancement of the health of mankind.

It was established on 1 April 1975 as a *non-profit* foundation under Japanese civil law and in accordance with an agreement between the governments of Japan and the United States. RERF was preceded by the *Atomic Bomb Casualty Commission* (ABCC), which was established in 1947 by the *US National Academy of Sciences* (NAS). ABCC initiated extensive health studies on A-bomb survivors in cooperation with the *Japanese National Institute of Health of the Ministry of Health and Welfare*, which joined the research program in 1948. When ABCC was reorganized to form RERF in 1975, it was deemed essential that research continue in full partnership between Japan and the US. Accordingly, RERF is managed by a bi-national Board of Directors, and its scientific research activities are guided by the annual recommendations of a bi-national Scientific Council. Funds for RERF's operation are provided by both governments.

B.2 The major organizations involved in the development of the system of protection

Starting from the studies and analyses of population exposure to ionising radiation and related health risks made by the above cited organizations, the *International Commission on Radiological Protection* (ICRP), and in the US the *National Council on Radiation Protection* (NCRP), formulated the system of radiation protection. Recommendations concerning measurements, quantities and units in radiation protection are made by the *International Commission on Radiation Units and Measurements* (ICRU).

[13] http://www.rerf.jp/

B.2.1 International Commission on Radiological Protection (ICRP)

ICRP[14] is an independent, international non-governmental organisation, comprising experts in various fields from around the world. It is a registered charity (a not for-profit organisation) in the United Kingdom, and has a scientific secretariat in Ottawa, Canada.

ICRP was established in 1928 at the second *International Congress of Radiology* to respond to growing concerns about the effects of ionizing radiation being observed in the medical community. At the time it was called the *International X-ray and Radium Protection Committee*, but was restructured to better take into account the uses of radiation outside the medical area and given its present name in 1950.

Since 1928, ICRP has developed and maintained the *International System of Radiological Protection* used world-wide as the common basis for radiological protection standards, legislation, guidelines, programmes, and practice. The System has been developed by ICRP, based on both the current understanding of the science of radiation exposures and effects, and value judgements. These value judgements take into account societal expectations, ethics, and experience gained in application of the system.

ICRP regularly publishes fundamental recommendations describing the overall system of radiological protection and other more detailed recommendations concerning the protection of workers and the public against ionising radiation, including guidance on all aspects of protection against ionizing radiation. The most recent fundamental recommendations were issued by ICRP in 2007 in Publication 103 (ICRP, 2007) following eight years of discussions, involving scientists, regulators, and users around the world. Publication 103 formally replaces the Commission's previous Recommendations issued in 1990 (ICRP, 1991), and updates, consolidates, and develops the additional guidance on the control of exposure from radiation sources issued since 1990.

ICRP offers its recommendations to regulatory and advisory agencies and provides advice intended to be of help to management and professional staff with responsibilities for radiological protection. Legislation in most countries adheres closely to ICRP recommendations. The International Atomic Energy Agency (IAEA) "*International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources*" is based heavily on ICRP recommendations, and the International Labour Organization (ILO) "*Convention 115, Radiation Protection Convention, General Observation 1992*", refers specifically to the recommendations of ICRP.

B.2.2 International Commission on Radiation Units and Measurements (ICRU)

ICRU[15] - originally known as the *International X-Ray Unit Committee* and later as the *International Committee on Radiological Units* - was conceived at the First International Congress of Radiology (ICR) in London in 1925 and officially came into being at the second ICR in Stockholm in 1928. The primary objective was to propose an internationally agreed upon unit for measurement of radiation as applied to medicine. The ICRU established the first internationally acceptable unit for exposure, the roentgen, in 1928. From 1950 ICRU expanded its role significantly to embrace a wider field. That is, ICRU has as its principal objective the development of internationally accepted recommendations regarding:

[14] http://www.icrp.org/
[15] http://www.icru.org/

- quantities and units of radiation and radioactivity;
- procedures suitable for the measurement and application of these quantities in diagnostic radiology, radiation therapy, radiation biology, nuclear medicine, radiation protection, and industrial and environmental activities;
- physical data needed in the application of these procedures, the use of which assures uniformity in reporting.

ICRU is committed to collect and evaluate the latest data and information relevant to the problems of radiation measurement, and to recommend in its publications the most appropriate values of radiation quantities and the most acceptable and safest techniques for current use. Indeed, it has continued to recommend new quantities and units as the need arose, for example, *absorbed dose* (1950), the *rad* (1953), *fluence* (1962), *kerma* (1968), and *cema* (1998). The latest report on fundamental quantities and units is Report 85a-Revised (ICRU, 2011).

The Commission maintains close contacts with the International Commission on Radiological Protection (ICRP), the International Organization for Standardization (ISO), the International Bureau of Weights and Measures/Bureau International des Poids et Mesures (BIPM) and the International Committee for Weights and Measures/Comité International des Poids et Measures (CIPM), as well as with other international and national organizations including the International Atomic Energy Agency (IAEA), the World Health Organization (WHO), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) and the US National Council on Radiation Protection (NCRP).

B.2.3 National Council on Radiation Protection (NCRP)

In the USA the organization which develops and elaborates the radiation protection system is the *National Council on Radiation Protection* (NCRP).

NCRP[16] has been active in the areas of radiation protection and measurements since its inception as "*The Advisory Committee on X-Ray and Radium Protection*" in 1929. It was originally established to represent all of the national radiological organizations in the United States on a collective, scientific basis and to serve, in essence, as the United States national analogue of the *International X-Ray and Radium Protection Committee* which was created in 1928 and, subsequently, evolved into ICRP. NCRP originally operated as an informal association of scientists seeking to make available information and recommendations on radiation protection and measurements. With the vast increase in the use of radiation that took place in the 1940s and 1950s, the NCRP's program expanded significantly to meet the new needs and, subsequently, it was recognized that continuation of the informal mode of operation was inappropriate. As a result, NCRP was reorganized and chartered by the US Congress in 1964 as the *National Council on Radiation Protection and Measurements*. One of the main objectives of NCRP, stated by the Charter, is to develop basic concepts about radiation quantities, units and measurements, about the application of these concepts, and about radiation protection. It should be noted that while the Charter recognizes the importance and the national character of the NCRP, it does not make the Council a governmental body; it is a private corporation. Also, the Charter does not entitle the Council to congressional appropriations. NCRP is a nongovernmental, not-for-profit, public service organization and has status as an educational and scientific body which is tax exempt. The recommendations promulgated by the Council provide the scientific basis for radiation protection

[16] http://www.ncrponline.org/

efforts throughout the country. Governmental organizations, including the *Nuclear Regulatory Commission*, the *Public Health Service*, the *Environmental Protection Agency* and state governments utilize NCRP's recommendations as the scientific basis of their radiation protection activities.

The fundamental principles of a radiation protection system - justification, optimization and dose limitation - as initially stated in ICRP Publication 26 (ICRP, 1977) were adopted and applied by the NCRP in its recommendations Report N. 91 (NCRP, 1987). The principles were reiterated by both ICRP (ICRP, 1991) and NCRP (NCRP, 1993). However, after establishing the basic radiation protection recommendations the activities of the NCRP and ICRP diverge (Kase, 2004). The USA current recommendations related to radiation safety practice are based on the principles and dose limits specified in NCRP Report N. 116 (NCRP, 1993), where an interesting comparison can also be found between risk values, dose limits, organ or tissue weighting factors and radiation weighting factors recommended by ICRP in its Publication 60 (ICRP, 1991) and NCRP in its Report N.116. ICRP Publication 60 has been superseded by Publication 103, therefore a new comparison of the main recommendations of ICRP and NCRP would be desirable.

B.3 The major organizations involved in issuing standards, recommendations, or regulations in radiation protection

The major organizations devoted to issuing recommendations and regulations for radiation protection are the *European Atomic Energy Community* (EURATOM) and some agencies of the *United Nations*. The *United Nations* is a family of organizations. Also known as the *United Nations* system, it is made up of the *United Nations Secretariat*, the *United Nations programmes and funds*, and the *UN specialized agencies*. The programmes, funds and agencies have their own governing bodies and budgets, and set their own standards and guidelines. Together they provide technical assistance and other forms of practical help in virtually all areas of economic and social endeavour.

B.3.1 European Atomic Energy Community (EURATOM)

The famous *Treaties of Rome,* signed in Rome in March 1957, established a *European Economic Community* (EEC), that is a generalised common market, and a *European Atomic Energy Community*, better known as *EURATOM*[17], initially created to coordinate the Member States' research programmes for the peaceful use of nuclear energy and is still in force.

The general objective of the Treaty is to contribute to the formation and development of Europe's nuclear industries, so that all the Member States can benefit from the development of atomic energy, and to ensure security of supply. At the same time, the Treaty guarantees high safety standards for the public and prevents nuclear materials intended principally for civilian use from being diverted to military use. It is important to note that EURATOM's powers are limited to peaceful civil uses of nuclear energy. The *European Atomic Energy Community* has not merged with the *European Union* and therefore retains a separate legal personality, while sharing the same institutions.

One of the numerous specific tasks of EURATOM, established by the Treaty, is "..to establish uniform safety standards to protect the health of workers and of the general public and ensure that they are applied". Indeed, EURATOM has, since 1959, been issuing its own basic standards designed to protect

[17] http://ec.europa.eu/energy/nuclear/euratom/euratom_en.htm

workers and the public against the dangers resulting from ionising radiation. The EURATOM standards are legally binding since they must be transposed into the legislation of Member States. These basic standards are issued in a EURATOM Directive. The latest - still in force - was issued in 1996 (EC, 1996) to make allowance for the 1990 Recommendations of ICRP (ICRP, 1991) and the 1980 Recommendations of ICRU (ICRU, 1980). However, a new Directive (Directive 2013/59), which takes into account the latest Recommendations of ICRP (ICRP, 2007), was issued in January 2014 (EC, 2014) and must be transposed into national legislation by 6th February 2018.

B.3.2 International Atomic Energy Agency (IAEA)

IAEA[18] is the world's center of cooperation in the nuclear field. It was set up as the world's "Atoms for Peace" organization in 1957 within the United Nations family and works with its Member States - and multiple partners worldwide - to promote safe, secure and peaceful nuclear technologies. The Agency regularly issues recommendations containing the basic standards for protection against ionising radiation and the safety of radiation sources. The aim is to bring radiological protection and radiological safety standards into line internationally. The most recent recommendations "*International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources*" were issued in 1996 (IAEA, 1996) and make allowance for the contents of ICRP Publication 60 (ICRP, 1977). The *Basic Safety Standards* (BSS) were drawn up under the auspices of the IAEA with the *United Nations Food and Agricultural Organization* (FAO), the *International Labour Organization* (ILO), the *OECD's Nuclear Energy Agency* (NEA), the *Panamerican Health Organization* (PAHO) and the *World Health Organization* (WHO).

New Basic Safety Standards, which take into account the latest ICRP Recommendations of Publication 103 (ICRP, 2007), were approved in September 2011 by the *Board of Governors* and have been issued as a *Safety Requirements* publication in the *IAEA Safety Standard Series*, as an interim version (IAEA, 2011). They will be issued as a final publication in Arabic, Chinese, English, French, Russian and Spanish.

IAEA publishes many more documents under different series.
(see http://www-pub.iaea.org/MTCD/publications).

B.3.3 World Health Organization (WHO)

WHO[19] is the directing and coordinating authority on international health within the United Nations' system. 194 countries and two associate members form WHOs membership. WHO is responsible for providing leadership on global health matters, shaping the health research agenda, setting norms and standards, articulating evidence-based policy options, providing technical support to countries and monitoring and assessing health trends. WHO experts produce health guidelines and standards, and help countries to address public health issues. WHO also supports and promotes health research. Through WHO governments can jointly tackle global health problems and improve people's well-being. In the 21st century, health is a shared responsibility, involving equitable access to essential care and collective defence against transnational threats.

[18] http://www.iaea.org/

[19] http://www.who.int/

B.3.4 United Nations Food and Agricultural Organization (FAO)

FAO[20] is a United Nations specialized agency, whose mandate is to achieve food security for all, to make sure people have regular access to enough high-quality food to lead active and healthy lives. This implies to raise levels of nutrition, improve agricultural productivity, better the lives of rural populations and contribute to the growth of the world economy. FAO has 194 Member Nations, two associate members and one member organization, the European Union. Representatives of members meet at the biennial FAO Conference to review global governance policy issues and international frameworks, as well as to evaluate work carried out and to approve the budget for the next biennium.

B.3.5 International Labour Organization (ILO)

The ILO[21] is the international organization responsible for drawing up and overseeing international labour standards. It is the only "tripartite" United Nations agency that brings together representatives of governments, employers and workers to jointly shape policies and programmes promoting *Decent Work*[22] for all. This tripartite structure makes the ILO a unique forum in which the governments and the social partners of the economy of its 185 Member States can freely and openly debate and refine labour standards and policies.

ILO is devoted to promoting social justice and internationally recognized human and labour rights, pursuing its founding mission that labour peace is essential to prosperity.

B.3.6 Committee on Radiation Protection and Public Health (CRPPH of OECD/NEA)

The Committee on Radiation Protection and Public Health (CRPPH) is an organization within OECD/NEA[23] (Organization for Economic Co-operation and Development/Nuclear Energy Agency). One of the key objectives of the CRPPH is to facilitate the peaceful uses of radiation that can improve the living standards taking into account radiation protection and the ALARA principle.

Its activities are aimed at introducing and maintaining different measures to reinforce or maintain a high level of radiation protection. On this subject the organization works closely with the ICRP. The CRPPH aims to establish a work environment free of known hazards for nuclear power and waste management operations, as well as for medical and other industrial uses of ionising radiation. The organization provides advice to the member states of the OECD on radiation protection regulation.

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20 http://www.fao.org/

21 http://www.ilo.org

22 The *Decent Work concept* was formulated by the ILO's constituents – governments, employers and workers – as a means to identify the Organization's major priorities. It is based on the understanding that work is a source of personal dignity, family stability, peace in the community, democracies that deliver for people, and economic growth that expands opportunities for productive jobs and enterprise development.

23 http://www.oecd-nea.org/

B.4 Other stakeholders

B.4.1 Networks

Networks are an efficient way for implementing radiation protection, the ALARA principle and ALARA culture in different exposure situations. These networks are successful because they provide a platform to exchange experience on operational radiation protection and ALARA implementation and allow the exchange of views from different stakeholders.

An overview of different networks related to radiation protection and ALARA is given here.

B.4.1.1 European ALARA Network (EAN)

The aim of the European ALARA Network (EAN[24]) is to promote a wider and more uniform implementation of the ALARA principle for the management of worker, public and patient exposures in all situations and to provide a focus and a mechanism for the exchange and dissemination of information from practical ALARA experiences. Topical issues of common interest are identified and examined in the network to further improve the practical implementation of ALARA.

The network started in 1996 as one of the European Framework programs for Research and Development and was transformed into a legal entity in 2005 as a non-profit organization under French law with an administrative board managing the network and a steering group that discusses the activities of the network.

Currently 20 countries are participating in the Steering Committee with experts from different fields: radiation protection authorities, research institutes, industrial companies, hospitals, services etc. The focus of the network was first oriented to the use of the ALARA principle in industry and research, later the scope was broadened to include the medical field and the NORM-industry. A further broadening of the scope is foreseen in the coming years to include all exposure situations.

The activities of the ALARA network involve the gathering and processing of international and national information from member countries on radiation protection and ALARA. This is done through the organization of workshops, surveys and of course through networking with other organization.

Within EAN, a sub-network has been created for the radiation protection authorities: ERPAN[25] - European Radiation Protection Authorities Network. The ERPAN aims to promote communication between national regulatory authorities including the exchange of information, requirements and experiences on the process of authorisation and inspection methods employed in European countries in order to promote the ALARA principle. It also aims to help improve the operational efficiency of radiation control across Europe while recognising the different regulatory systems within the various countries.

[24] http://www.eu-alara.net

[25] ERPAN has a special page in the EAN website and publishes information through European ALARA Newsletter.

Besides exchanging information the EAN also provides technical support assistance in the creation of new ALARA networks in Central and East Europe (RECAN)[26] and Asia and the Pacific region (ARAN)[27]. The network has been also involved in the creation of the European ALARA Network for Naturally Occurring Radioactive Materials (EANNORM) and the European Medical ALARA Network (EMAN).

B.4.1.2 European NORM Association (ENA)

In 2017 September a new association, The European NORM Association (EAN), has been formed by merging the European NORM networks EANNORM and EU NORM. The mission and objectives of ENA are to promote and advance radiation protection in the context of exposure to NORM by operating as a European platform and forum for discussion, dissemination and exchange of information, training and education and by supporting scientific knowledge and new directions of research related to NORM issues. The overarching objective of the ENA is to support the management of NORM in compliance with European standards and Member State legislation and according to best practice.

B.4.1.3 European Radiation Dosimetry Group (EURADOS)

The European Radiation Dosimetry Group (EURADOS[28]) is a non-profit association for promoting research and development and European cooperation in the field of the dosimetry of ionizing radiation. It is registered in the German Register of Societies.

It is a network of more than 50 European institutions (Voting Members) and 250 scientists Associate Members), which includes experts, reference and research laboratories, and dosimetry services.
Its main bodies are: the General Assembly, composed by the Voting Members, the Executive Board, the Council and several Working Groups.

It is financed by sponsoring institutions, voting members, levies raised for activities organized by EURADOS (annual meetings, training courses and inter-comparison exercises), and projects funded by the European Union.

Its activities encompass coordination of working groups, organization of scientific meetings and training activities, organization of inter-comparisons and benchmark studies in the areas of individual monitoring for external and internal exposure, retrospective dosimetry, environmental radiation monitoring, diagnostic and interventional radiology, nuclear medicine, radiation therapy and computational dosimetry.

B.4.1.4 Heads of European Radiological Competent Authorities (HERCA)

HERCA was created in 2007 at the initiative of the *French Nuclear Safety Authority* (ASN) to initiate an exchange of knowledge and experiences in order to facilitate practical and harmonized solutions to important regulatory issues in radiation protection.

26 http://recan.webplus.net

27 http://www.asian-alara.net

28 http://www.eurados.org/

HERCA is a voluntary association of the Radiation Safety Authorities in Europe where they work together in order to identify common significant radiation protection issues and propose harmonization and/or practical solutions towards a common approach for these issues, whenever possible.

HERCA is also a forum for the Radiation Safety Authorities to share information and experience, in particular with regard to the practical transposition of European legislation and international recommendations.

The goal of HERCA is to contribute to a high level of radiation protection throughout Europe by:

- building and maintaining a comprehensive European network of chief radiation safety regulators in Europe;
- promoting exchange of ideas and experience and learning from each other's best practices;
- discussing and where appropriate, expressing its consensus opinion on significant radiological protection and regulatory issues;
- developing, by consensus whenever possible, a common approach to radiological protection issues;
- having an impact on the practice of radiological protection, within the States of HERCA members, through the voluntary implementation of outcomes from HERCA work.

B.4.1.5 Information System on Occupational Exposure (ISOE)

The Information System on Occupational Exposure (ISOE[29]) was created in 1992 to provide a forum for radiological protection experts from both utilities and national regulatory bodies to discuss, promote, and co-ordinate international co-operative undertakings in the area of worker protection at nuclear power plants. NEA and IAEA are the co-secretariat of ISOE. ISOE members are utilities and regulatory bodies from all over the world. The ISOE program includes the occupational exposure information covering about 91% of the world's operating commercial power reactors and provides a forum for exchange and discussion on operational radiation protection aspects. The organizations products include the ISOE database, technical support and analyses, ISOE ALARA symposia and topical reports.

B.4.2 Professional societies

B.4.2.1 International Radiation Protection Association (IRPA)

The International Radiation Protection Association (IRPA[30]) provides a medium for communication to those engaged in radiation protection activities in order to advance radiation protection worldwide, to provide protection of persons and the environment from the hazards caused by radiation and thereby to facilitate the safe use of medical, scientific, and industrial radiological practices for the benefit of mankind. In its objective it encourages research, publications and education on radiation protection, and review of universally acceptable radiation protection standards or recommendations through the international bodies concerned.

[29] http://www.isoe-network.net
[30] http://www.irpa.net/

IRPA provides support for international meetings for the discussion of radiation protection issues. The International Congresses of IRPA, held every four years since 1966, are the most important of these meetings.

B.4.2.2 International Organization for Medical Physics (IOMP)

The International Organization for Medical Physics (IOMP)[31] was formed in January 1963 initially with 4 affiliated national member organizations. The Organization had a membership in 2010 of 80 national member organizations and 6 regional organizations.

IOMP is charged with a mission to advance medical physics practice worldwide by disseminating scientific and technical information, fostering the educational and professional development of medical physics and promoting the highest quality medical services for patients. Information on IOMP activities, development priorities, and external relations are given in her strategic policy document.

IOMP works together with International Organizations such as IAEA, WHO and ILO to strengthen the role of Medical Physicists. ILO has recently classified medical physicists as a profession in the International Standard Classification of Occupations-08 (ICSO-08) under physics and astronomy, which is an important reference document for governments for recognition and classification of occupations.

IOMP collaborates with professional bodies such as IRPA and ICRP and international organizations such as WHO and IAEA in promoting the development of medical physics and safe use of radiation and radiological equipment technology.

IOMP is collaborating with professional organizations in development of a professional certification system for medical physicists that can be implemented on a global basis. To provide guidance on education, training and professional development of medical physicists, IOMP is publishing some policy documents on such issues.

B.4.2.3 European Federation of Organizations in Medical Physics (EFOMP)

The European Federation of Organizations in Medical Physics (EFOMP)[32] was founded in 1980. The current membership covers 35 national organizations and 3 affiliated national organizations which together represent more than 5000 physicists and engineers working in the field of Medical Physics.

Its aims are:

- to foster and coordinate the activities of National Member Organizations, collaborating with national and international organizations;
- to encourage exchange and dissemination of professional and scientific information, and exchange of Medical Physicists between countries;
- to develop guidelines for education, training and accreditation programmes;
- to make recommendations on the responsibilities, organisational relationships and roles of Medical Physicists;

[31] http://www.iomp.org/

[32] http://www.efomp.org/

- to encourage the formation of Organizations for Medical Physics where such organizations do not exist;
- to work for Europe-wide recognition of Medical Physics as a regulated profession in all member states as well as Medical Physics as a health care profession.

B.4.2.4 European Society of Radiology (ESR)

The European Society of Radiology (ESR)[33] was founded in December 2005 by merging the European Congress of Radiology (ECR) and the European Association of Radiology (EAR), thus establishing a single house of radiology in Europe. It is an apolitical, non-profit organisation, exclusively and directly dedicated to promoting and coordinating the scientific, philanthropic, intellectual and professional activities of radiology in all European countries.

B.4.2.5 European Federation of Radiographer Societies (EFRS)

The European Federation of Radiographer Societies (EFRS[34]) was founded in 2008 by 27 professional societies of radiographers. In 2015 already 38 radiographer societies from 32 countries in the geographical region of Europe are registered as full members, 49 educational institutions from 25 countries joined as affiliate members and are cooperating in the EFRS educational wing. Also one trade union joined as affiliate member.

The role of the European Federation of Radiographer Societies (EFRS) is to represent, promote and develop the profession of radiography in Europe, within the whole range of medical imaging, nuclear medicine and radiotherapy and moreover everything that is directly or indirectly related or beneficial to this role, everything in the broadest meaning

B.4.2.6 European Federation of Non Destructive Testing (EFNDT)

The European Federation of Non Destructive Testing - EFNDT[35] - was founded in May 1998 in Copenhagen at the 7th European Conference for Non-Destructive Testing (ECNDT). 27 national NDT societies agreed to set up a powerful organization at the European level. Full membership is open to national NDT societies, one per country. Associate membership is open to all applicable organizations worldwide.

The overall mission of EFNDT is to bring together the resources of the national societies and organizations involved in NDT and related topics in Europe to create a more effective and more valuable voice for industry, the professions, users and the wider community.

Specific objectives include:

- Promote the importance of NDT and related research, development, training, certification and accreditation to improve reliability and safety of all the engineered items which are essential to everyday living.
- Act as the voice of the community of NDT in Europe.

[33] http://www.myesr.org

[34] http://www.efrs.eu/

[35] http://www.efndt.org/

- Encourage contacts between NDT Societies in Europe and other organizations with an interest in NDT.
- Represent the European community of NDT in meetings with European Commission and related bodies.
- Contribute to the elimination of trade barriers.
- Organise conferences and seminars, including the European Conference on NDT (ECNDT).
- Organise working groups and make studies in the field of NDT.
- Publish journals and reports in the field of NDT.
- Provide support for training certification examinations.
- Promote the execution of R&D projects and their exploitation.
- Promote certification systems for personnel and/or organizations in Europe.

Non-destructive testing and technical diagnostics covers the whole field of inspection and condition monitoring technologies used to protect the safety of the public, equipment, installations and the environment.

B.4.2.7 American Association of Physicists in Medicine (AAPM)

The American Association of Physicists in Medicine (AAPM)[36] is a scientific and professional organization, founded in 1958, composed of more than 7500 scientists whose clinical practice is dedicated to ensuring accuracy, safety and quality in the use of radiation in medical procedures such as medical imaging and radiation therapy. They are generally known as medical physicists and are uniquely positioned across medical specialties due to their responsibility to connect the physician to the patient through the use of radiation producing technology in both diagnosing and treating people. The responsibility of the medical physicist is to assure that the radiation prescribed in imaging and radiation therapy is delivered accurately and safely.

One of the primary goals of the AAPM is the identification and implementation of improvements in patient safety for the medical use of radiation in imaging and radiation therapy.

B.4.2.8 National radiation protection associations

The national radiation protection associations provide a local platform for information exchange on radiation protection and ALARA issues. Because they are embedded in a country or a region they provide detailed information on the national standards for radiation protection and national regulatory aspects. Most of the national radiation protection associations are also member of the IRPA association in an effort to further harmonise the radiation protection approach worldwide.

References

BEIR, 2006. Health risks from exposure to low levels of ionizing radiation. BEIR VII Phase 2. Committee to Assess Health Risks from Exposure to Low Levels of Ionizing Radiation. National Research Council of the National academies. The National Academies Press, Washington D.C.

[36] http://www.aapm.org

EC, 1996. COUNCIL DIRECTIVE 96/29/Euratom of 13 May 1996 laying down basic safety standards for the protection of the health of the workers and the general public against the dangers arising from ionizing radiation (O.J. L 159. 29.6.96).

EC, 2014. Council Directive 2013/59/Euratom of 5 December 2013 laying down basic safety standards for protection against the dangers arising from exposure to ionising radiation, and repealing Directives 89/618/Euratom, 90/641/Euratom, 96/29/Euratom, 97/43/Euratom and 2003/122/Euratom. OJ L 13, 17.1.2014.

IAEA, 1996. International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources, IAEA Safety Series No.115.

IAEA, 2014. Radiation Protection and Safety of Radiation Sources: International Basic Safety Standards. IAEA SAFETY STANDARDS SERIES No. GSR Part 3. International Atomic Energy Agency, Vienna, 2014

ICRP, 1977. Publication 26. Recommendations of the ICRP. Ann. ICRP 1 (3), 1977.Superseded by ICRP Publication 103.

ICRP, 1991. International Commission on Radiological Protection. 1990 Recommendations of ICRP. ICRP Publication 60. Annals of the ICRP 1991; 21 (1-3).

ICRP, 2007. International Commission on Radiological Protection. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Annals of the ICRP 2007; 37 (2-4).

ICRU, 1980. International Commission on Radiation Units and Measurements. Report 33 "Radiation Quantities and Units" Pub: Washington D.C.

ICRU, 2011. International Commission on Radiation Units and Measurements. Report 85-a Revised "Fundamental Quantities and Units for Ionizing radiation", Journal of the ICRU, vol.11, Oxford University Press.

Kase K. (2004) Radiation Protection Principles of NCRP. Health Phys. 87(3): 251-257; 2004.
NCRP, 1987. Recommendations on limits for exposure to ionizing radiation. Bethesda, MD NCRP Report 91, 1987.

NCRP, 1993. National Council on Radiation Protection and Measurements. Limitation of exposure to ionizing radiation :Bethesda, MD NCRP Report 116, 1993.

UNSCEAR, 2010. United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR 2008 REPORT Sources and Effects of Ionizing Radiation., Vol. I, SOURCES. Report to the General Assembly Scientific Annexes A and B. United Nations, New York, 2010. (http://www.unscear.org/unscear/en/publications.html).

UNSCEAR (2011) United Nations Scientific Committee on the Effects of Atomic Radiation. UNSCEAR 2008 REPORT Vol II Effects of Ionizing Radiation. Report to the General Assembly, Scientific Annexes C, D and E. United Nations, New York, 2011

APPENDIX C EXAMPLES OF ALARA CHECK-LIST

C1. Checklist to be used at the design stage of a facility

These ALARA design checklist sections are presented in a publication from OECD/NEA related to Occupational Radiological Protection Principles and Criteria for Designing New Nuclear Power Plants[37].

SECTION 1. GENERAL SYSTEM/COMPONENT DESIGN

- Will this engineering change constitute a change in the Final Safety Analysis Report (FSAR) radiation zone classifications both pre-accident and post-accident?
- Will this engineering change affect area radiation monitor performance characteristics, set points or plant location? If yes, then contact Plant Health Physics for setpoint change determination.
- Are radiation-damage-resistant and environmentally qualified materials used, when applicable, to reduce need for frequent replacement?
- Are flow restrictions minimized in radioactive systems?
- Are flanged connections provided, where possible, for quick disconnects and access for hydrolyzing?
- Are electrical quick disconnects used in design to minimize maintenance time?
- Are components designed to facilitate draining, flushing, cleaning and decontaminating by mechanical or chemical means?
- Can flushing, draining or cleaning operations be performed remotely?
- Are vertical versus horizontal type heat exchangers used with contaminated fluids on the tube side?
- Have robots or robotic devices been evaluated to reduce or eliminate worker residence time?

SECTION 2. SYSTEM LAYOUT, COMPONENT CONFIGURATION, ACCESSIBILITY, AND ACCESS CONTROL OF RADIATION AREAS

- Is all equipment located in the lowest dose rate area where practicable?
- Have recent radiation surveys been reviewed to ensure that equipment is located away from hot spots and local high radiation areas?
- Are components located in radiation areas designed for quick removal and installation (e.g., overhead lift points)?
- Is piping, equipment, insulation, and shielding designed for quick removal and replacement?
- Are cable and conduit runs designed and routed through low radiation areas?
- Are permanent platforms, walkways, stairs, or ladders provided to permit prompt accessibility for servicing or inspection of components located in higher radiation areas?
- Are recording and control devices easily read or manipulated from and located in accessible areas with low radiation levels?

[37] Occupational Radiological Protection Principles and Criteria for Designing New Nuclear Power Plants, NEA#6975, ISBN: 978-92-64-99142-2, 2010, Available online at: http://www.oecd-nea.org/rp/reports/2010/nea6975-criteria-new-plants.pdf

- Are local indicators (e.g., temperature, pressure) positioned and designed to be read from outside radiation areas using remote viewing devices or remote readouts?
- Have permanent or removable transport devices such as monorails or jib cranes been considered?
- Are components requiring frequent maintenance, calibration or inspection located in low radiation or areas?

SECTION 3. RADIOACTIVE WASTE

- Has consideration been given in the design to minimize mixed waste and/or radioactive waste generation during installation, operation and maintenance?
- Has consideration been given to the handling and transport of radioactive waste materials?
- Are radioactive waste capabilities available for solid radioactive waste, flushing and decontamination liquids?
- Has consideration been given in the design to minimize or preclude the generation of gaseous contamination during installation, operation, and maintenance?

SECTION 4. PERMANENT AND TEMPORARY SHIELDING AND GEOMETRY

- Has the use of permanent shielding been considered to maintain radiation levels at a minimum and prevent the need for repeated installation of temporary shielding?
- Are attachment lugs incorporated into design to allow easy installation of temporary shielding blankets?
- Are proposed shield designs based on SSES plant-specific source term information?
- Is the use of lead minimized in shielding design due to the material's hazardous classification and have alternate materials been considered (e.g., steel, water, concrete)?
- Has streaming through penetrations for piping, ducts, electrical conduits, etc., been reduced by using shadow shields?
- Are penetrations positioned high in shield walls to minimize radiation levels in accessible areas as a result of primary and secondary radiation beam scatter?
- If shielding is not practical at installed locations, can equipment be moved to lower radiation areas for maintenance or inspections?
- Has shielding been provided for between individual components that constitute substantial radiation sources to help maintenance and inspection personnel servicing other specific components in the area?
- Has provision been made for transporting/storing radioactive components or sources using pigs or specialized shields?
- Does this engineering change affect components such that existing shielding calculations require review and/or change? (e.g., pipe support removals, piping replacement)

If the change involves: Surfaces which may become contaminated or measures to facilitate decontamination or contamination control, then:

SECTION 5. DECONTAMINATION AND CONTAMINATION CONTROL

- Are wall and floor surfaces sealed for ease of decontamination?
- Are surfaces that might become contaminated, non-porous, free from cracks, and sharp corners?
- Have measures been taken to reduce the spread of contamination from the source (curbing, slopes to drains, sumps, etc.)?

- Are drainage provisions (including drain vents) made for all sample points to collect overflow and flushing water?

If the change involves: material, construction or assembly techniques, shapes, flow patterns or choices of equipment in direct contact with systems containing radioactive material, then:

SECTION 6. SOURCE REDUCTION, MITIGATION OF RADIATION FIELD BUILDUP AND CRUD CONTROL

- Are components in contact with primary coolant comprised of low cobalt, nickel, manganese, etc., alloys to minimize activation products that contribute to plant radiation fields? If NO, please explain why such alloys cannot feasibly be used.
- Do design features incorporate highly corrosion-resistant materials to minimize material losses to primary coolant?
- Are proper lubricants and favorable geometry's utilized to prevent loss of material by erosion of load-bearing hard facings (typically Stellite) and subsequent entry into primary coolant?
- Have smooth surfaces been considered to reduce crud deposition?
- Are new systems or components chemically preconditioned to minimize the rate of corrosion product release and render surfaces less susceptible to deposition and incorporation of activated corrosion products?
- Have potential crud traps been identified and eliminated where possible? For example: Avoid crevices, deadlegs, 90 degree turns, and areas of low flow that can become crud traps.
- Have crud removal methods such as flushing, recirculation, hydrolyzing, chemical decontamination or other means been incorporated to reduce personnel exposures?
- Are drains provided at low points in systems to flush out crud?

If the change involves: valves containing radioactive fluids and/or related components, then:

SECTION 7. VALVES CONTAINING RADIOACTIVE FLUIDS

- Do valves located inside high radiation areas have sufficient space for maintenance?
- Are full ported valves (opening inside valve same as pipe) used to prevent interference with process fluids during valve cycling and minimize crud traps?
- Have all relief valves and rupture discs in the area been considered for possible radioactive releases and subsequent replacement?
- Are valves designed in the stem-up position to facilitate maintenance and prevent crud traps? (Note: Some valves require installation with stem oriented several degrees off the vertical for proper functioning.)
- Have valves designed with bonnet cavities been avoided?

If the change involves: piping containing radioactive fluids and/or related components, then:

SECTION 8. PIPING CONTAINING RADIOACTIVE FLUIDS

- Are radioactive systems designed to minimize deadlegs, standpipes, and low points?
- Are large radius pipe bends of at least five pipe diameters used instead of elbows to reduce deposition or resins, sludge and crud products?

- Are pipe fittings, pipe bends, pipe tees and field welds minimized to reduce collection of radioactive material?
- Are butt welds used instead of socket welds to allow smoother interior system surfaces?
- If a tee is used in piping, is the normal flow through the straight portion and are branch lines located above the run?
- Are lines carrying spent resins or slurries run as vertically as possible?
- Are short runs of pipe used to reduce accumulations of radioactive materials?
- Are long runs of pipe sloped to minimize crud buildup?
- To reduce crud traps, are connections on piping made above the centerline?
- Are orifices installed in vertical piping runs where possible?
- Is piping diameter sized to preclude the need for orifices, maximize fluid velocity while minimizing settling and to minimize line plugging?
- If pass-through piping may cause high radiation levels in an area during routine maintenance, has consideration been given to relocating the pipe or for providing shielding?
- Are all lines carrying spent resins or radioactive slurries designed without flow control valves or orifice?
- Can lines that are subject to plugging to be backflushed or flushed with lower activity liquid?
- Has piping containing radioactive fluids been routed to take credit for shielding effects of equipment and structures?
- Are piping and hanger supports designed to adequately support temporary shielding?
- Has electropolished stainless steel piping been considered in order to retard radiation field buildup in out-of-core piping?
- Does design incorporate piping designed to contain radioactive material under both normal and off-normal conditions?
- Are hot tap clean outs with ball valves used in lieu of flanged connections where feasible?
- Is the flow in pipes other than sample and radioactive waste lines laminar to prevent crud or other radioactive material deposition due to eddying?
- Are systems containing radioactive slurries provided with check valves or strainers at interface with liquid systems?

If the change involves: tanks containing radioactive fluids and/or related components, then:

SECTION 9. TANKS CONTAINING RADIOACTIVE FLUIDS

- Are tanks designed with sloping or round bottoms and/or spargers to remove radioactive sediments?
- Are tank drain valves located away from the tank bottom to minimize exposure?
- Are isolation valves on lines connected to tanks containing spent resins, sludge, or concentrates, located to minimize deadlegs?
- Are all liquid radioactive waste tanks and floor drains provided with a vent collection system and are vents filtered to minimize collection of solids in system?
- Have cleanout connections been provided on tanks?
- Are tank overflow lines directed to the radioactive waste collection system?
- Can air versus water spargers be used to prevent nozzle blockage?

If the change involves: pumps containing radioactive fluids and/or related components, then:

SECTION 10. PUMPS CONTAINING RADIOACTIVE FLUIDS

- Is seal water taken from contaminated sources avoided where possible?
- Has consideration been given to incorporation of seal-less pumps?
- Are provisions made to drain pump casings or equipment?
- Is controlled leakage purge across journal sleeves used to avoid entry of particles into primary coolant?

If the change involves: filter or filter systems in radioactive systems, then:

SECTION 11. FILTERS IN RADIOACTIVE SYSTEMS

- Are screens or filters provided in vent lines from radioactive tanks and can they be replaced or cleaned easily?
- Are provisions made for remote removal and installation of filters where predicted dose rates are very high?
- Are gaseous effluent filters in areas large enough for remote handling tools and temporary shielding to be used?
- Are filters used throughout the system standardized and able to be backflushed?

If the change involves: heating ventilation and air conditioning systems, then:

SECTION 12. HEATING, VENTILATION, AND AIR CONDITIONING WHICH POTENTIALLY CONTAIN RADIOACTIVE EFFLUENTS

- Are welded seams employed in air ducts?
- Have high efficiency filters, electrostatic precipitators, and charcoal filters been considered to minimize the transport of radioactivity?
- Are high flow rates and temperatures maintained in HVAC systems prior to filtration?
- Have provisions been made to reduce localized airborne radioactivity by techniques such as leakage collection, ventilation and component selection?
- Is ventilation flow from areas of low potential airborne activity to areas of high potential activity?
- Is the number of directional changes in ductwork containing airborne radioactive material minimized to prevent contamination build-up?

If the change involves: process instrumentation controls or sampling systems, then:

SECTION 13. PROCESS INSTRUMENTATION AND CONTROLS/ SAMPLING SYSTEMS

- Have instrument systems using intermediate fluids or fluid isolation been considered?
- Are instrument taps located above the midplane?
- Are local sample points minimized with piping or conduit routed to a central shielded location?
- Are sampling systems designed for high continuous purge flow for quick, accurate samples routed to shielded or remote locations, including accident conditions?

If the change involves: radiation detection instrumentation or monitoring systems, then:

SECTION 14. RADIATION MONITORING SYSTEMS

- Does electrical circuitry allow indication of detector failure?
- Are local alarms and readouts provided?

If the change involves: new facility design or significant change to an existing facility, system or group of like components, then:

SECTION 15. NEW FACILITY DESIGN/SIGNIFICANT DESIGN CHANGES TO EXISTING FACILITIES/SYSTEMS

- Have systems and components been segregated such that low, moderate and high radioactivity sections are separated and located with the corresponding systems or components to the extent possible?
- Have shielded chases been considered for high radiation piping, especially pass-through piping runs?
- Are valves shielded from high activity equipment by using valve galleries?
- Have skid-mounted systems been designed with shielding between high and low activity portions or adequate spacing to allow future addition of shielding?
- Are shield doors, shield plugs or labyrinths used to reduce exposure while ensuring ability to access and remove components?
- Is access control provided for in the design of new areas or change of existing areas?
- Are barriers provided to limit access to areas that are greater than 1000 mR/hr?
- Are proper equipment decontamination facilities available nearby to equipment, in low radiation areas?
- Are decontamination areas provided with laydown area for additional storage of equipment prior to decontamination?
- Are services such as electrical power, water, and air located reasonably close to radiation work areas?
- Is the system laid out to maximize the effective distance between radiation sources and work locations?

C2. Pre/post job ALARA check-List

These check-lists are extracted from IAEA Safety Series n°21 on Optimization of Radiation Protection in the Control of Occupational Exposure.

Pre-job Review Check-list	**Yes**	**No**	**To be studied**
• Is there previous experience of similar operations? • Has it been taken into account? I. Actions on sources • Before shutdown: chemical filtration? • Decontamination? • Is it possible to maintain water in circuits? • Removal of a highly radioactive material? • Other? II. Protection • Biological shielding: is it fixed, mobile, integrated with the machinery? • Against contamination: is a glovebox available? • Shielding? • Is shielding integrated with the tools? • Static containment? • Dynamic containment? • Sprinkling and drainage? • Adapted individual protection? III. Volume of work under conditions of exposure • Is this an essential task? • Is the procedure optimal? • Is the task correctly scheduled? • Is the task to be executed entirely in an irradiated zone? • May some operators be moved to a distance? Is the number of operators justified? • Is the distribution of work optimized? • Can doses be spread between operators? • Are there special tools for reducing doses? • Is there an opportunity for remote control or robotics? • Can clothing be modified to facilitate the work? • Is there an opportunity for improvement to ambient conditions • (e.g. temperature, lighting)? Is there an opportunity for radio communications? • Is there an opportunity for televisual surveillance? • Is there an opportunity for easier access? • Is handling equipment available? • Are there adequate superstructures (e.g. scaffolding)? • Are there standing and procurement areas? • Are there procedures for packing equipment and packaging waste? • Are there procedures for the removal of material?			

Post-Job Debriefing
Task: Meeting participants:
All the questions must be answered as fully as possible so that the task might be assessed and used as the basis for modifications during future work. • Were the tools and equipment required for the operation available at the right time? • Was the zone prepared and ready for your task on your arrival? • Were the protection measures suitable for the task executed in this zone? • How much time did you have to prepare the task? Was this long enough? • Did other tasks interfere with yours? • Was the work location kept clean and orderly so as to ease your work? • Was the full team aware of its exposure? Did you insist on this exposure being limited as much as possible? • Was the entire team aware of the site dose targets? Was the team motivated? • Were there any problems of co-ordination with other specialities, other departments or other workers? • What problems did you encounter that could have resulted in higher doses?

C3. Checklist in the medical field

Below are the "10 Pearls for Radiation Protection of Patient and Staff using Fluoroscopy Mobile X-ray Equipment" extracted from posters from the EMAN Network and available at (https://rpop.iaea.org/RPOP/RPoP/Content/Documents/Whitepapers/poster-patient-radiation-protection.pdf
and https://rpop.iaea.org/RPOP/RPoP/Content/Documents/Whitepapers/poster-staff-radiation-protection.pdf).

- Provide necessary education and training in radiation protection and use of X-ray equipment
- Avoid the primary beam
- Smallest possible radiation field. Collimate around area of interest
- Shortest possible fluoroscopy time
- X-ray tube under the patient
- Detector as close as possible to the patient
- Use lead apron. It reduces the radiation dose to about 10%
- Shortest time as possible near the patient
- Keep distance
- Stay away if you are pregnant.

C4. Inspection / Audit ALARA Checklist in the medical field

Example of questions which are related to ALARA and they can be included in a checklist for inspection/audit:

	Yes	No	To be studied
Quality assurance			
A Quality Assurance system is implemented			
Quality control of equipment is carried out on a normal basis			
Personnel training			
Training of medical and paramedical personnel on radiation protection and ALARA			
Are seminars on radiation protection and ALARA organized on a normal basis by the Radiation Protection Officer?			
Areas			
Appropriate designation of areas			
Appropriate shielding of examination/therapy rooms			
Patient exposure			
Individualization of examination parameters (e.g. position, kV, mA)			
Use of specific paediatric examination protocols according age/weight/other			
Establishment of local DRLs			
Comparison of local DRLs to the respective national ones			
Investigation of pregnancy before the exposure			
Radiation protection			
Use of Pb aprons, collars, glasses by the personnel?			
Staff protection in operating rooms?			
Presence of persons other than the patient in the room during the examination?			
Accompanying persons?			
Protection means for accompanying persons?			
Use of immobilization means for paediatric examinations?			
Gonad shielding?			
Exposure is limited at the area of interest?			
Investigation of repetitions –causes			
Evaluation of findings			
Measures for repetitions minimization			

APPENDIX D THE MONETARY VALUE OF THE UNIT OF DOSE

D1. Introduction

The optimal allocation of resources to reduce doses ALARA, taking both social and economical factors into account, can be particularly challenging especially when resources are limited. A point will also be reached where there are progressively smaller dose savings achieved despite increasing investment (known as the "law of diminishing returns"). To facilitate the implementation of ALARA in this situation, ICRP proposed (as early as 1973) that the costs associated with the various options for radiation protection be compared with the benefits of the corresponding reduction in exposure (ICRP, 1973). In particular, ICRP suggested the use of cost–benefit or cost-efficiency analysis where the benefit (or efficiency) could be monetized with the aid of a reference value per unit of collective dose averted often referred to as the "alpha value" or "alpha (α)" (with units of euros per man-Sievert, €/H.mSv).

D2. Determination of the reference monetary values of the unit of collective dose

Introducing a reference monetary value per unit of collective dose enables a value to be given to the reduction in life-expectancy resulting from radiation exposure. This could also be considered as giving a value to the human life because, in the case of a dose-effect relationship, it is possible to quantify the risk of cancer for a given level of exposure. Different approaches have been used to calculate a reference monetary value as outlined below.

The "human capital" method

The human capital method is a well-known economic method usually employed in health economics and is based on the assumption that the monetary value allocated to one year of life is equal to the average contribution by an individual to the national wealth. The idea being that each individual shares equally in this wealth and therefore contributes to social well-being. If someone dies as the result of an accident or illness before the theoretical age corresponding to his life expectancy, there is a loss of contribution to the national wealth. This was the first concept to emerge that considered economy in an effort to allocate a monetary value to human life.

A common indicator of national wealth is the gross national product (GNP) per head, i.e. the average individual contribution to the national economy each year, and this could also be considered as the monetary value for one year of life (for example, in 2014, GNP per head in France was around EUR 31,000).

The monetary value associated with a fatal effect (or equivalent) due to ionising radiation is obtained by considering a loss of life expectancy of around 16 years (ICRP,1977). This being the case, using the probability of occurrence of such an effect induced by a dose of one man.sievert of 5.6 x 10^{-2} (ICRP, 2007), for a population of adult workers, the monetary value of the health effects associated with one man.sievert is estimated by multiplying 16 years by the monetary value of one year and by the probability of occurrence of a fatal health effect. The calculation used to obtain this value is summarised in the boxes below, using the 2014 French data.

- The monetary value of one year of life lost is equal to the annual GNP per head: EUR 31,000/year
- A fatal radiation-induced health effect corresponds to around 16 years of life lost (cf. ICRP Publication 26 (ICRP,1977)).
- The monetary value of a radiation-induced health effect is equal to:
  16 years × EUR 31,000/year = EUR 496,000
- The probability of occurrence of a radiation-induced health effect per man.sievert is equal to: 5.6 x 10-2 (cf. ICRP, Publication 60).
- The monetary value of one man.sievert is then equal to:
  EUR 496,000 x 5.6 x 10^{-2} = EUR 27,800/man-sievert

Other approaches to assess the statistical monetary value of the human life

The human capital method has the advantage of being simple to use and non-discriminatory (the same value applies to every individual), but it has also attracted criticism for being restrictive by focusing only on the revenue and not taking into account other costs like medical expenses; the preference of individuals; the willingness to live, etc. The method may also raise ethical issues. One approach that would avoid such issues is to expand the scope of the human capital method and also consider other costs such as direct costs (medical costs from the treatment of cancer itself, general expenses that will have not been spent without cancer – expertise, transport, …) and indirect costs (suffering, emotional cost, …) to determine a new alpha value. This approach leads to an overall increase in the alpha value.

Recently, the most popular approach that can be found in literature to assess the statistical value of human life has been the *willingness-to-pay* approach. The concept is the following: the monetary value of the human life is measured by considering the sum that a person (or a group of persons) will pay to avoid a given statistical risk. The sum is measured with the help of specifically designed surveys and interviews. This approach allows other factors to be taken into account such as the desire to live longer and the preference of the individuals to be protected against a specific risk (certain risks raising more concerns than others). Another advantage is that it highlights the monetary effort expended on the reduction of the risk.

Some concrete examples;

- In France, a commission set up to evaluate the statistical value of life has used the willingness-to-pay approach and proposed a value of EUR 1.5 million in 2001 (Boiteux, 2001), later increased to EUR 3 million (or EUR 115,000 /year 'saved') in 2013 (Quinet, 2013).
- In 2012, the OECD performed a meta-analysis of 856 results and concluded that the statistical value of the human life in OECD countries ranges between USD 1.5 and 4.5 millions with an average of USD 3 millions[38].
- In 2015, the Nuclear Regulatory Commission of the United States of America gathered the value of human life indicators used by different federal agencies (willingness-to-pay approach) and selected the mean value (alpha value was calculated to be USD 5,130 /man.rem) (NRC, 2015).

[38] www.oecd.org/env/politiques/vvs

D3. Making allowance for risk aversion

Alongside the global principle of keeping doses ALARA, ICRP also recommend to reduce the distribution of individual exposures and give priority to protecting the most exposed individuals. As such, ICRP introduces the notion of equity in the optimization process. Giving consideration to these objectives can be achieved by introducing the concept of *risk aversion* (ICRP, 1983) which allows for more resources to be spent protecting the most exposed individuals.

D4. A Proposal of a model integrating the individual dose dimension

In order to introduce the consideration of individual dose levels in the monetary value of the man-sievert, a model was developed in the 1990's (Lochard, 1996). The model has been designed in such a way as to reduce collective exposure while reducing exposure breakdown, with priority being given to high exposure levels and is expressed as follows:

$$\alpha_{ref}(d) = \alpha_{base}\left(\frac{d}{d_0}\right)^a$$

where:

$\alpha_{ref}(d)$	=	monetary value of the man.sievert for individual exposure level d
α_{base}	=	reference monetary value of the man.sievert
d_0	=	lower value of individual dose range from which the aversion can be applied
d	=	annual individual exposure level
a	=	coefficient representing degree of aversion ($a = 0$ when $d<d_0$, $a\geq 0$ when $d \geq d_0$)

The curve of this relationship is as shown below: it illustrates a system where the monetary values of the man.sievert increase as individual exposure levels "d" increase and also when the distribution of exposures (expressed in the "d/d_0" factor) increase – the risk aversion being driven by the coefficient "a".

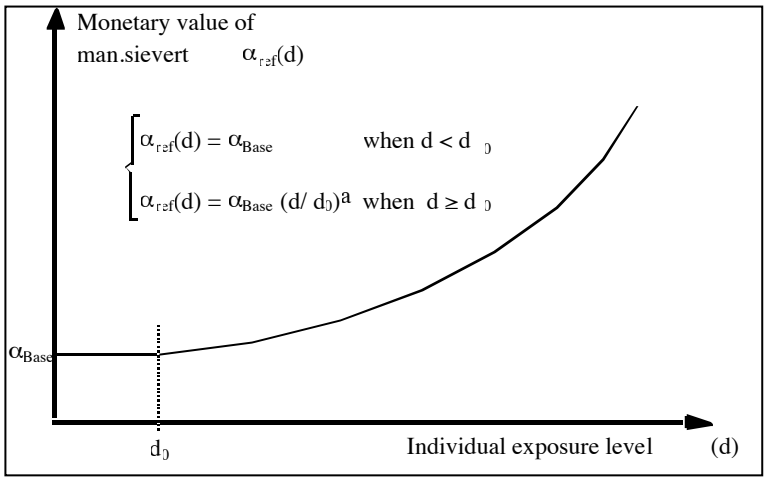

Figure D1. Generic diagram of model for system of monetary values for the man.sievert with aversion

In practice, in order to implement this model, it is necessary to select a value to the three parameters: ' α_{base}', 'd_0' and ' a':

- The value of 'α_{base}' represents the basic monetary value of the health detriment associated with the unit of collective exposure. The Human Capital method presented above can be used for this evaluation.

- The value of 'd_0' corresponds to the upper level of individual dose below which the aversion to the distribution of exposures is not considered ($\alpha = \alpha_{base}$). This value depends upon the degree of acceptability of risk for the exposed population. In case of occupational exposure for example, it seems reasonable to adopt the value corresponding to the limit of individual exposure for the public (1 mSv/year).

- The 'a' coefficient reflects the degree of aversion to the distribution of individual exposures. It can be demonstrated that 'a' must be greater than 1 to satisfy the three mentioned objectives (Schneider, 1997) but kept < 2 so $\alpha(d)$ does not increase in too greater proportion. In case of occupational exposures, a range of values between 1.2 and 1.8 seems reasonable.

D5. Examples of monetary values of the unit of collective dose in the nuclear field

In 2002 and 2009, the European Technical Centre of the ISOE Network (www.isoe-network.net) conducted surveys among regulatory bodies and nuclear utilities regarding the alpha value either set by authorities or internally by the utilities. The results (ISOE, 2003, ISOE, 2012) are available on the ISOE Network website[39].

In 2017, a new survey was conducted (ISOE, 2018) with replies received from 20 countries, gathering 27 answers in total. In most cases, the regulatory bodies do not use an alpha value (the main reason being that the nuclear utility of the country has already set up an alpha value system, so there is no need for the regulatory body to tackle the topic) and the choice of the values falls ultimately on the responsibility of the nuclear utility. Exceptions to this include the Office for Nuclear Regulation (United Kingdom) that uses a single alpha value (GBP 2.67 million) and the Slovak Public Health Authority (UVZSR) and the Czech State Office for Nuclear Safety (SÚJB) who use a system of values, depending on the level of individual doses and also the type of exposure under consideration (planned, medical etc.).

The majority of the nuclear utilities that answered the survey has a system of monetary values of the unit of collective dose. The system can be based on one unique alpha value or a set of alpha values, increasing with the level of individual doses of the concerned personnel or with the level of collective dose (averted by the radiation protection investment). The unique alpha values range from EUR 570/man.mSv to EUR 5,000/H.mSv (thus a wide array of values, for the same risk; depending on the difference of rationale applied when establishing the values, national economic conditions etc.).

Of course, the sets of alpha values used by different utilities, increasing with the level of exposure, cannot be directly compared. But for interest, the minimum value reported was EUR 44/man.mSv (at

[39] ISOE European Technical Centre Information Sheet 34 – Man-Sievert Monetary Value Survey, 2002 Update, 2003.
ISOE European Technical Centre Information Sheet 55 – Man-Sievert Monetary Value Survey, 2012 Update, 2012.

TEPCO, Japan, for exposure in the order of 1 mSv) and the maximum EUR 8,900/man.mSv (at TEPCO, Japan, for exposure > 20 mSv). Most of the alpha values reported were in the order of EUR 2,000-3,000/man.mSv. All of the values are presented on the Figure below. It should be noted that the various nuclear utilities update the alpha values with regard to the prevailing economic conditions (*e.g.* increase in the GNP).

The utilities do not use the system on a day-to-day basis but typically between 1 to 10 times a year maximum, and only for major decisions and investment that will impact radiation protection, budget, availability of the plant etc. The large-scale decontamination of circuit and equipment is the most frequent example reported. Hence, the alpha values are not only used by the radiation protection department but also by top level managers, to help them quantify the potential impact of a radiation protection investment. As a result, the alpha value is commonly considered as a valuable tool to provide objectivity and transparency in the decision-making. Naturally, the alpha value is not the only factor in the final decision being encompassed in a much broader process that takes into account other criteria.

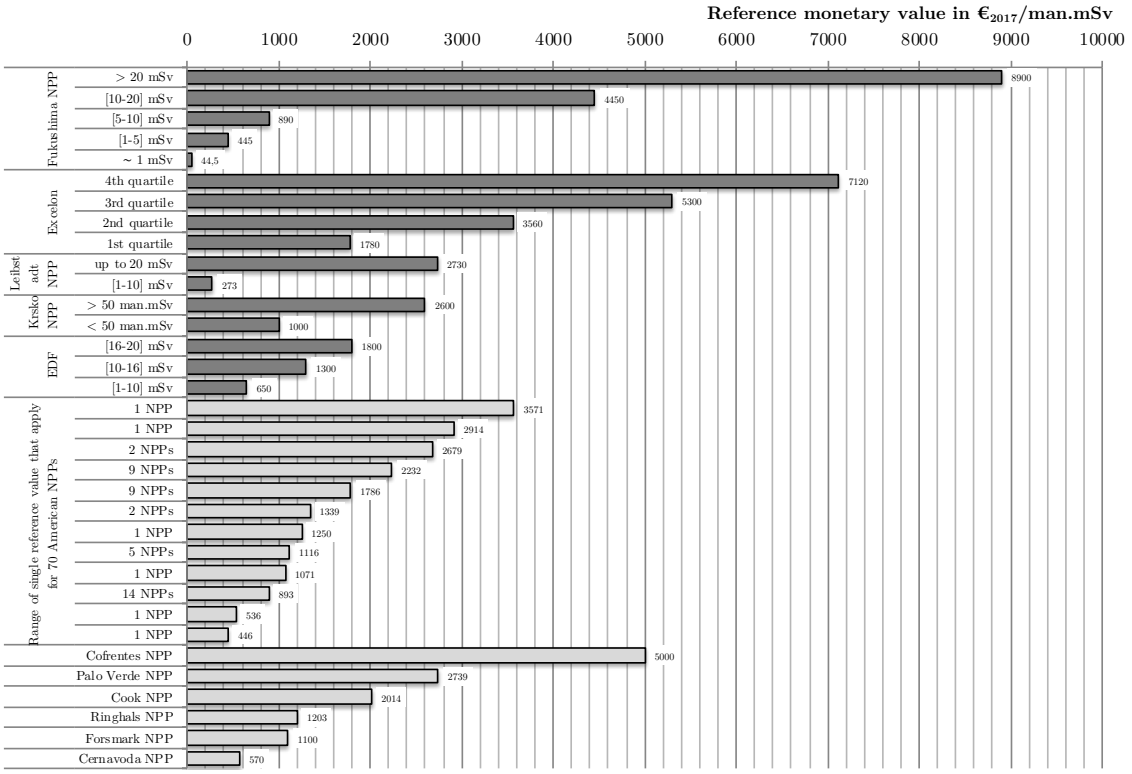

Figure D2. Monetary values of the unit of collective doses from an ISOE Survey performed in 2017.

References

Boiteux, 2001. Transports : choix d'investissements et coût des nuisances, Boiteux M. Commissariat Général du Plan, Juin 2001.

ICRP, 1973. Implication of the Commission Recommendations that doses be kept as Low as Readily Achievable, ICRP Publication 22, 1973.

ICRP, 1977. Recommendations of the ICRP. ICRP Publication 26. Ann. ICRP 1 (3).

ICRP, 1983. Cost-Benefit Analysis in the Optimization of Radiation Protection. ICRP Publication 37. Ann. ICRP 10 (2-3).

ICRP, 2007. The 2007 Recommendations of the International Commission on Radiological Protection. ICRP Publication 103. Ann. ICRP 37 (2-4).

ISOE, 2003. ISOE European Technical Centre Information Sheet 34 – Man-Sievert Monetary Value Survey, 2002 Update, 2003.

ISOE 2012. ISOE European Technical Centre Information Sheet 55 – Man-Sievert Monetary Value Survey, 2012 Update, 2012.

ISOE, 2018 Survey on the Values and Uses of the Monetary Value of the Man.Sievert (in 2017), ISOE European Technical Centre Information Sheet 61, 2018
Lochard, 1996. Lochard J., Lefaure J., Schieber C., Schneider T., A model for the determination of monetary values of the man-sievert, J. Radiol. Prot., 1996, Vol. 16, N°3, 201-204.

NRC, 2015. Reassessment of NRC's Dollar Per Person-Rem Conversion Factor Policy, Bone A., NUREG-1530, Revision1, Draft Report for Comment, Nuclear Regulatory Commission, 2015.

Quinet, 2013. L'Evaluation Socio-économique des Investissements Publics, Quinet E. (président), Commissariat Général à la Stratégie et à la Prospective, Septembre 2013.

Schneider, 1997. T. Schneider, C. Schieber, L. Eeckhoudt, C. Gollier, 'Economics of Radiation Protection: Equity Considerations', Theory and Decision,Vol. 43, N°3, November 1997.

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