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Optimisation in Operational Radiological Protection

A Report by the Working Group on Operational Radiological Protection of the Information System on Occupational Exposure

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NUCLEAR ENERGY AGENCY
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- to provide authoritative assessments and to forge common understandings on key issues as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

Specific areas of competence of the NEA include safety and regulation of nuclear activities, radioactive waste management, radiological protection, nuclear science, economic and technical analyses of the nuclear fuel cycle, nuclear law and liability, and public information. The NEA Data Bank provides nuclear data and computer program services for participating countries.

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FOREWORD

Since the issuance by the International Commission on Radiological Protection (ICRP) of its Publication 60, the system of radiological protection that it describes has been implemented in national legislation and international standards. Through this implementation, many areas have been identified in which the system of radiological protection could evolve to better serve the needs of radiation protection regulators, practitioners and other interested parties.

To better address their needs, the ICRP has launched a very open process of recommendation development, which has involved the collection of comments from many quarters. The member countries of the OECD Nuclear Energy Agency (NEA) have been extremely interested in this process: through the NEA they have developed two consensus reports on this subject and have held dialogues with the ICRP Chair on several occasions to voice their views and opinions on various stages of ICRP suggestions, ideas and text.

As a result of this input, and of the ICRP's own processes of information gathering and synthesis, the ICRP has begun to develop new recommendations, which it expects to finalise in 2005. ICRP Committee 4 has launched a Task Group on the Optimisation of Protection, with the goal of producing a new ICRP recommendation to supplement the information that can already be found in earlier ICRP publications (9, 22, 26, 37, 55, 60, 63, 75 and 82). The focus of this new work will be to place these earlier works in the context of new General ICRP Recommendations, which are also in the process of being developed.

The Information System on Occupational Exposure (ISOE), focusing on the operational aspects of radiological protection, has great interest in assuring that new recommendations from the ICRP will be operationally useful. Therefore, to assist the NEA Committee on Radiation Protection and Public Health (CRPPH) in its work of contributing its viewpoints to the ICRP, the ISOE Programme agreed that its views of the key aspects of operational radiation protection could also form useful input to the ICRP. For this purpose, the ISOE Steering Group created, at its November 2001 meeting, the Working Group on Operational Radiological Protection (WGOR) to address these issues.

Within the context of the current ISOE programme of work, the WGOR was mandated to identify the key areas of importance in operational radiological protection at nuclear power plants, particularly as they relate to optimisation processes. This work takes into account other work in this area, particularly the recent IAEA Safety Series Report Number 21. The final report of the Working Group will be circulated widely, through NEA and IAEA channels, and will be offered to the CRPPH and to the ICRP as input to their consideration of new ICRP recommendations. The specific terms of reference for the Working Group are as follows:

1. The Working Group will identify the areas of operational radiological protection that it feels are key, and that should be reflected, in some fashion, in ICRP recommendations. This will include the Group's views on the role of collective dose for workers, on protective action levels, on effluent release options, and on nuclear emergency planning.
2. The Working Group will develop experience-based "case studies" to illustrate how operational optimisation can be applied in practice in various situations, such as:
   - dose management;
   - during outage periods;
   - during normal operation;
   - large specific tasks such as PWR steam generator or vessel head replacement;
   - gaseous and liquid releases.
3. The Working Group will develop practical and operational views on "Empowerment of the Workforce", which has been cited as a key aspect of new ICRP recommendations.
4. The Group will be prepared to provide views, on behalf of the ISOE Steering Group, to the CRPPH on the implications of draft ICRP Recommendations on operational radiological protection.
5. The Working Group will present its final draft results to the fall 2003 meeting of the ISOE Steering Group. The ISOE Steering Group will discuss this topic during a special topical session, and will instruct the Working Group how to proceed to finalise its report.

The Working Group finalised its report, based on input from the ISOE Steering Group, and presented this work at the IRPA-11 meeting held in May 2004. This work is presented herein.

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EXECUTIVE SUMMARY

Operational radiological protection focuses very strongly on assuring that exposures to workers and the public are maintained as low as reasonably achievable, (ALARA). While this concept is central to the day-to-day management of exposures, the complex nature of exposures and exposure situations mandates a flexible approach to the implementation of radiological protection actions. The increasing participation of various stakeholder groups in decision-making processes further suggests the need for flexibility to assure the appropriate incorporation of these views. Although philosophy, policy, regulations and guides are necessary as a framework for operational applications, these guiding tools should remain rather non-prescriptive to allow the radiological protection practitioner to appropriately find the optimum option for radiological protection on a case-by-case basis.

In this context, radiological protection professionals are very interested in the current development of new recommendations from the International Commission on Radiological Protection, ICRP. To assist in this development, the NEA/IAEA Information System on Occupational Exposure (ISOE) developed, through its Working Group on Operational Radiological Protection (WGOR) this report. The objective of this work is to remind the international radiological protection community, and the ICRP, of the practical aspects or radiological protection that should be reinforced by any new ICRP recommendations, and to identify areas where further practical guidance would be useful. As such, this report provides several key messages regarding the current approach to operational radiological protection. Based on these, this report also provides suggestions to the ICRP for the development of its new recommendations, designed to facilitate their application. These messages and suggestions are summarised here, and further elaborated in the body of the report. Appendices provide some practical examples as illustration.

Optimisation of public protection

A key objective of radiological protection professionals is to optimise protection for members of the public and at the same time for workers and the environment. This does not, however, mean the minimisation of dose. Rather, current practice in optimisation applies the ALARA philosophy and the use of best available technology (BAT) such that exposures resulting from a practice are appropriately managed and protective actions are agreed upon by all relevant stakeholders. This is a qualitative and quantitative process, which is adapted to address each given situation. From a practical standpoint, it should be remembered that protection options that decrease public exposure at the expense of significant worker exposures are not seen to be ALARA. Current practice also uses collective dose is an effective planning tool for comparing options, but recognises that this should not be used to assess public detriment.

Optimisation of worker protection

Worker exposures are also managed using a process of quantitative and qualitative optimisation. Total worker dose, sometimes referred to as worker collective dose, is a commonly and effectively used tool. Generally, worker exposures are broken into management categories (e.g. type of worker, type of task, type of work) for work planning, for management of ongoing work, and for post-work experience assessment and feedback. However, flexibility in applying the ALARA philosophy and in assessing compliance is necessary because collective dose must be considered simultaneously with individual doses. As such, it is felt that having an individual dose limit/constraint of 20 mSv/a can be restrictive, and can actually lead to increases in collective dose.

Empowerment of the workforce

Current practice encourages and empowers workers themselves to contribute significantly to optimisation of protection, broadly through work planning and management. Worker operational experience is a key basis for the improvement of work efficiency. This can result in several positive effects that are closely linked together, including; lower doses, higher safety, higher efficiency, lower costs, and more efficient use of resources. While it should be remembered that national and plant-specific approaches to the implementation of work planning and management practices may differ significantly (responsibility, distribution of tasks, etc.), the objectives of work management can be achieved by many approaches. Work management will include the consideration of many more aspects of worker health and safety than simply radiological protection.

The use of tools in optimisation

Many quantitative tools have been developed to assist in the assessment and management of radiological protection risks. These include such things as dose models, pathway analyses, time and motion studies, and "alpha-values" for balancing of risk and benefit. With the growing importance of stakeholder involvement, more qualitative and process-oriented tools are now being developed to supplement this pool of quantitative tools. This trend suggests the need for flexibility in management and regulatory approaches to allow the most appropriate solutions to be found on a case-by-case basis. These things being said, however, the application of a generic level, on the order of a few 10s of μSv/a, below which the need for regulatory control, if any, would be reduced, would be welcomed by the nuclear industry.

ALARA in old plants *versus* ALARA in new plants: Are they equal?

The new draft ICRP recommendations suggest that optimisation of protection below a given dose constraint is a central priority. This tends to focus on the process, not on the results as long as they are not above a specified constraint. As such, the site-specific philosophies for the implementation of optimisation and ALARA can be equivalent at different sites, while yielding different results.

Optimisation of decommissioning

The optimisation of protection in decommissioning is framed within international guidelines and recommendations, and more specifically within national policy objectives. National choices such as waste conditioning requirements, material release regulations, site release regulations, and safe-store requirements can have a significant effect on the optimisation choices that are made. Within national policy and regulatory frameworks, levels that are eventually chosen for the release of sites and materials, and their associated requirements for verification of compliance, should not result in excessive worker exposures. Worker exposures should be key elements that are considered when national decommissioning policy is developed.

International aspects of optimisation

The nature of international recommendations implies a certain level of agreement on common approaches. To assure that common approaches leave sufficient national and local flexibility, the level of common approaches and understanding needed to effectively optimise public and worker protection should to be discussed. One area where the need for guidance is clear is the national and international management of itinerant worker exposures. Here, it is understood that the responsibility for the management and optimisation of worker protection lies at all levels. The management and optimisation of worker protection is the responsibility of the worker's employer. The facility causing worker exposure is responsible for optimising protection for all doses received at that facility. National regulatory authorities are responsible for reviewing worker doses and their compliance with dose limits. This being said, expanding the use of practical tools, such as “dose passports”, should be explored nationally and internationally.

Based on these current practices, and on the evolutionary direction that the new ICRP recommendations have been taking, it is felt that further discussion and/or guidance is needed from the ICRP in several areas.

- The new concept of the dose constraints may be interpreted as a regulatory instrument for compliance considerations. Some of the proposed dose constraints (e.g. 0.3 mSv/a as opposed to 1.0 mSv/a, or 20 mSv/a as opposed to 100 mSv per 5 years and a max of 50 mSv in any single year) seem to be a tightening of restrictions that would cause a loss of operational flexibility. Yet there is a lack of scientific justification for such a tightening. The ICRP should provide a clear discussion of the rationale behind such tightening, and allow the flexibility of interpretation of these numbers.

- The new formulation of optimisation, including stakeholder involvement, is inherently judgmental and case-by-case, using quantitative and qualitative approaches. Efficient dose management seems to be focused increasingly on process elements rather than simply specific numerical results. As such, the ICRP should clearly state and highlight the need for operational flexibility to promote the implantation of this approach.

- Guidance is needed with regard to the practical application of optimisation. This includes discussion of elements to consider when agreeing on and demonstrating that protection solutions are optimised and doses are ALARA; when balancing worker and public exposures; when balancing individual and collective doses; or when evaluating the effectiveness of ALARA/optimisation programme. This should include a practical description of the use of matrix elements for characterising group dose.

- For practical dose management, guidance is needed concerning handling and communicating uncertainties, and with regard to the appropriate use and level of conservatism.

- In order to achieve an appropriate balance among workers, management and the regulatory authorities, understanding of roles and responsibilities of each will be essential.

The ISOE programme encourages the open dialogue of the broad radiological protection community on the development of new international recommendations. Because of the broad impact that new ICRP recommendations could have on national radiological protection regulations and implementation, it is suggested that any new ICRP recommendations should be reviewed from the legal standpoint, which will probably be necessary at the country level, and for their practical implications BEFORE they are finalised.

1. INTRODUCTION

The Information System on Occupational Exposure (ISOE) has, since its inception, focused on the sharing and analysis of information and experience to allow operational radiological protection professionals to most effectively and efficiently manage worker exposures. The practical and operational knowledge gained in over ten years of operating the ISOE programme forms a very complete basis for discussing the future of radiological protection. Thus, when the International Commission on Radiological Protection (ICRP) began work to develop new general radiological protection recommendations to replace those in ICRP Publication 60, the ISOE programme naturally became interested in contributing its knowledge of operational aspects to discussions.

From the papers, meetings and discussions that have emerged regarding new ICRP recommendations, it seems clear that the concept of optimisation will remain one of the pillars of radiological protection theory and practice. From the operational standpoint, the ISOE programme feels that optimisation is the central process in operational radiological protection, founded on the principle that, as a result of optimisation, exposures should be as low as reasonably achievable. The optimisation process uses many different tools and procedures and approaches, can be very complex or very simple, and may be qualitative or quantitative or both. In all cases it should be remembered that the desired result is exposures that are ALARA, not exposures that are minimised.

The body of this report identifies several of the most important operational aspects of optimisation, while examples of specific applications of optimisation are provided in appendix. Specifically with respect the development of new ICRP recommendations, several suggestions are made with respect to what should and should not be included. It is hoped that these operational suggestions will be broadly discussed by the international, operational radiological protection community, and will assist the ICRP in developing new recommendations that will truly improve the radiological protection of the public, workers and the environment.

2. OPTIMISATION OF PUBLIC PROTECTION

Nuclear installation operators work actively to limit the public exposure that facility operation could cause. Gaseous and effluent releases are limited and monitored, as are external exposures on the site, at the site boundary and at various off-site locations. To identify the most appropriate protective actions, public protection is optimised. This is achieved through a multi-aspect process to assure, as a minimum, compliance with regulations, but further, to assure that public exposures are "as low as reasonably achievable" (ALARA), and are appropriately balanced so as not to unreasonably expose workers. Stakeholders (e.g. the operator, the regulator, the local public) are involved, as appropriate for the situation under consideration, in this qualitative and quantitative process

Key messages

- The objective of radiological protection professionals is to use a process of optimisation to protect members of the public, workers and the environment. Minimisation of dose is not the objective.

- The ALARA philosophy and the use of "best available technology" (BAT) are both used in optimising protection options.

- Protection options that decrease public exposure at the expense of significant worker exposures are not seen to be ALARA.

- Collective dose is an effective planning tool for comparing options, but, particularly with respect to public exposures, is not used to assess public detriment.

Current approaches and practices

Within the current international system of radiological protection, as recommended by the ICRP, the optimisation process that could be used to in this situation is not well described. Operators have, however, developed their own approaches to exposure control, in collaboration with national regulators. In general, the actual environmental releases from nuclear power production facilities are significantly lower than allowed, regulatory limits, and thus result in modelled public exposures that are significantly lower than regulatory limits.

Practically speaking, licensed facilities have regulatory limits established on their gaseous and liquid discharges, and on any on- or off-site public, external exposure that may occur because of facility operation. Allowable numerical levels of discharges are expressed in various ways, including as total annual discharge (Bq/a), as a discharge rate (Bq/s), or as a discharge concentration (Bq/g or Bq/cm^3). External exposure limits can also be expressed in several ways, such as annual doses (mSv/a) or as dose rates (μSv/h). These regulatory limits are established, in general, based on rather conservative models. These models generally calculate the dose to a hypothetical, exposed group (sometimes referred to as the critical group) by looking at releases and the various pathways to exposure (inhalation, ingestion in food, ingestion in water, external exposure). The assumptions that are built into these models include such things as the age and sex of the exposed individuals, and their eating and living habits as these would affect their exposure. These habits can include where they physically live, often assumed to be at the site boundary, what they eat, often assumed to be food grown near the site boundary, and what they drink, often assumed to be ground and surface waters from near the site boundary. These rather conservative assumptions result in hypothetical, calculated exposures of the hypothetical exposed group, and form a scientific basis for fixing discharge limits.

In support of their protection efforts, and to validate the dispersion aspects of their models, facilities have developed extensive off-site exposure and environmental monitoring programmes. Dose rates and radionuclide releases are monitored using fixed monitoring devices (such as thermoluminescent dosimetry – TLDs, air particulate samplers, dose-rate detectors of various types), and the collection and analysis of various types of environmental samples (such as water, crops, grasses, and indigenous wildlife – particularly fish and shellfish).

Within this context, optimisation of public protection has generally been addressed in a qualitative fashion, using quantitative input (e.g. models and measurements) to assist the decision-making process. The types of situations that would be considered in an optimisation framework typically involve plant modifications that could have an effect on releases. This could include plant power upgrades, major component replacements (steam generators, reactor internals, condensers, etc.), or modifications to plant waste treatment facilities.

Practically, optimisation is then performed in the context of effluent release management. Two key concepts are applied. The first is to keep public exposures “as low as reasonably achievable” (ALARA), one of the basic principles of the system of radiological protection. The second concept is the use of “best available techniques” (BAT). This approach has been defined in different areas of non-radioactive effluent release optimisation, for example in the European Union *Integrated Pollution Prevention and Control (IPPC) Directive of 1996*. The IPPC Directive is concerned, in essence, with minimising pollution from various industrial point sources throughout the European Union.

ALARA and BAT are both optimisation approaches which have been applied in several NEA member countries for a number of years, complementing each other with the aim of limiting doses to humans, possible effects on non-human species, and radioactive effluent releases. ALARA and BAT are both moving targets, since developing societal values and advancing techniques may change what is currently regarded as “reasonably achievable” and “best available”.

Based on these concepts, there seem to be three basic approaches to the management of effluent releases from nuclear installations:

- Optimisation of protection of to achieve individual and/or collective dose to members of the public that are ALARA by using available techniques and appropriate measures at each source which may have a dose impact on members of the public.

- Further limitation of radioactive effluent releases from a single nuclear installation or source by using BAT at that source.

- Further reduction of concentrations of radionuclides in the environment, by optimising inputs to the environment from all man-made sources (based on information received through environmental monitoring), and implementing BAT at each source.

Decisions on effluent release management will be influenced by various technical, societal and policy factors. They will need to balance radiological impacts resulting from the collection and concentration of effluents, with those of effluent releases on human beings, including the issue of risk transfer, possible transboundary effects, etc. In addition, management decisions will need to take into account ecologically sensitive locations, and the capability to detect and monitor radionuclides in effluent releases and in the environment.

In the past, the optimisation of effluent releases from nuclear plants has been driven by prospective assessments of stochastic health effects on members of the public potentially exposed to radioactive emissions. This health-driven approach to protection has resulted in the development of nuclear abatement systems that concentrate and contain gaseous and liquid emissions converting them into solid waste forms for long term storage. Since 1992, the central organising principle of international environmental policy, sustainable development, has, in the non-radiological sector, moved beyond health-led emissions standards towards BAT techniques which reduce and eliminate emissions at source. Appendix 2 provides two examples of case studies where these concepts are applied in nuclear power plant situations.

The evolution of ICRP recommendations

Currently, ALARA and BAT approaches are used to optimise exposures to the public. However, there is very little international guidance, particularly from the ICRP, as to how these concepts should be implemented and their results assessed. Thus, in any future recommendations from the ICRP, guidance in the following areas would be useful:

- The assumptions made and parameters chosen for dose models tend to be very conservative. It would be useful for the ICRP to provide an indication of how uncertainties in models could best be understood in the context of protection decisions, and, in general, how much conservatism should be included in models.

- ICRP Publication 60 defined concept of collective dose, expressed as the sum of exposures to a defined group of exposed individuals. Mathematically, collective dose can, and has, been performed over large geographic areas and long time periods. It has been suggested that this approach overly aggregates information, making it less useful for comparison of protection options. The ICRP has thus suggested in new draft recommendation material, that doses to populations should be presented as a series of matrix elements, based on which decision makers will be in a better position to judge the implications of their protection choices. Guidance as to which matrix elements should presented, and how they could be considered in the decision-making process would be extremely useful. This is particularly important to the optimisation of protection in the case of effluent releases.

- In performing an optimisation analysis for public exposure from effluent releases, guidance on which elements and aspects should be considered, and on how optimisation should be performed would be very useful. Particularly, guidance addressing the eventual need to demonstrate compliance with regulatory requirements, for example, to be ALARA, is needed.

- Risk transfers have always presented a problem to the optimisation process as proposed by the ICRP. Of particular concern in the context of effluent releases, guidance is needed regarding how risks to the public and risks to workers should be compared when deciding on protection options. For example, how should options that would reduce public dose but increase worker dose (such as options that involve increased retention of effluents) be compared?

In addressing these concerns, practical considerations and implications should be kept in mind. The latest draft materials from the ICRP indicate that although dose limits will be kept for both workers and the public, single source dose constraint will also be established. A numerical value of 0.3 mSv/a has been suggested for the public dose constraint, and 20 mSv/a has been suggested for the worker dose constraint. While constraints are described in ICRP Publication 60 as tools for prospectively designing radiological protection options, regulators may interpret constraints as tools for demonstration of compliance. If this is the case, meeting these numerical values may become extremely difficult in some specific cases, requiring significant additional work by operators while not significantly increasing public or worker health and safety. Some examples of such possible situations include:

- exposure of the public (drivers included) during the transportation of radioactive materials;

- exposure of non-badge workers on nuclear sites, and particularly the definition of controlled versus supervised areas;

- exposure of the public in some mining situations where natural exposures are historically high;

- calculated exposures of the public at site boundaries;

- public and worker exposures at older facilities, where design or operating history has led to higher exposures, which might require a more flexible application of numerical values than for new plants.

In that there is no scientific justification for lowering the public exposure limit from 1.0 mSv/a to 0.3 mSv/a, this recommendation by the ICRP is taken as a management approach that could be used by regulatory authorities to address situations where groups or individuals are exposed to more than one source. The final approach to this question, however, should be taken by regulatory authorities.

It is suggested that the ICRP should keep these practical cases in mind when developing its new draft general recommendations and more detailed building block recommendations. Draft material should also continue to be issued for review and comment by stakeholders before finalisation.

3. OPTIMISATION OF WORKER PROTECTION

Worker dose, summed by task or by worker category, is currently one of the most effective and commonly used tools for the optimisation of worker exposures. It is used in all aspects of the optimisation process, from planning, to job implementation, to post-job assessment of lessons learned. As such, this tool should figure prominently in the presentation of new recommendations by the ICRP.

Key messages

- Optimisation is a key tool/process for the management of worker doses. Workers themselves contribute significantly to work planning, using their operational experience to improve work efficiency.

- Worker collective dose is an extremely useful tool for worker exposure management.

- Flexibility in individual dose management is useful for controlling collective dose and for assuring that individuals are equally protected. As such, having an individual dose limit/constraint of 20 mSv/a can be restrictive and can actually lead to increases in collective dose.

Current approaches and practices

As a planning tool, the estimate of total worker dose is used for the comparison of radiological protection options, and as an indicator of the level of administrative review and approval required for the task being considered. For example, when two or more approaches to a particular job are considered, total worker dose can be used as input when deciding which approach to take (e.g. the use of temporary shielding versus the installation of permanent shielding, or the use or not of system decontamination prior to work). Then, depending upon the level of the estimated total worker dose, many nuclear facilities have implemented a tiered system of review, the higher the pre-job estimated dose, the higher the level of approval required.

During the implementation of a task, total worker doses estimated in the planning phase are used to track dose expenditures. For single jobs, worker doses might be tracked on a daily basis over the period of the job. Planning and procedural adjustments may be made as a result of higher or lower than predicted doses. In some countries, dose underestimates or overestimates may provoke utility and/or regulatory investigations to determine why estimates were not accurate. In addition to these single job applications, in many nuclear facilities the worker doses for all jobs performed during long maintenance periods (e.g. refuelling in nuclear power plants) are tracked. As with dose tracking for single jobs, total maintenance period exposures can be tracked on a daily basis, and are one of the indicators used by plant management to gauge progress, and to inform decisions to adjust planning and/or procedures.

Once work has been completed, total worker dose estimates are used, particularly for repetitive jobs, in the analysis of lessons learned. Where detailed records are kept, specific work phases and aspects can be studied to identify changes that could be made to work more efficiently and effectively thus reducing exposures should the work be performed again at a later date.

During all these phases of work, it is important that exposures should be optimised. This is generally a facility requirement, and may also be a regulatory requirement. Operationally, optimisation is performed by such techniques as comparing procedural and protection options, and by benchmarking against similar jobs that have been previously-performed, or have been performed at other facilities. If historical or other benchmark records exist for a particular type of job, dose trends can also be compared as input to decisions regarding the need for planning or procedural modifications. Nuclear power plant outages are often tracked in this fashion.

The evolution of ICRP recommendations

One of the areas of the current ICRP system of radiological protection where there is not much operational guidance provided is that of worker exposure optimisation. Thus, in any future recommendations from the ICRP, guidance in the following areas would be useful:

- The current draft materials supplied by the ICRP indicate that worker exposure should be expressed as a series of matrix elements, similarly to public exposure. Operationally, total worker exposure, by task or work volume or time period, has been a useful tool and will continue to be used by industry. However, if a disaggregated presentation of worker exposure is to be suggested by the ICRP, the various elements that should be considered should be discussed, and guidance should be provided as to how the elements should be used in the optimisation of work.

- In general, facility management and regulatory authorities require that worker exposures should be as low as reasonable achievable, that is, the result of the optimisation process is exposures that are ALARA. As with the optimisation of public dose, the optimisation of worker dose tends to include qualitative and quantitative aspects. It would be useful if the ICRP would provide guidance as to the elements to be considered, from the scientific standpoint, when deciding that a particular approach is optimum or reasonable, and will result in doses that are ALARA. Clearly, any ICRP guidance in this area should not be prescriptive.

- Exposure of specially trained or skilled workers who may, from time to time, exceed 20 mSv in a single year, but not 50 mSv in any year or 100 mSv over a five year period. In fixing its recommendations for worker dose constraints/limits, the ICRP should clearly express the scientific considerations on which these numerical values are based.

4. EMPOWERMENT OF THE WORKFORCE

Much of the operational knowledge needed to efficiently manage worker exposures rests with the workers themselves. Exposures can be reduced at the same time as work efficiency can be improved through the application of good work management practices. Previous work by the ISOE programme[1] provided detailed descriptions of many aspects of how the effective selection and management of work could shorten the time needed for maintenance jobs and maintenance outages as a whole, and thus save dose and money. To harness the knowledge and experience of the workforce for this effort, actively engaging the workforce in decision-making processes is essential.

Key message

- Work management empowers workers. The linked effects of good work management include:
  - lower doses;
  - higher safety;
  - higher efficiency;
  - lower costs; and
  - more efficient use of resources.
- National and plant-specific approaches to the implementation of work management practices may differ significantly (responsibility, distribution of tasks, etc.), but the objectives of work management can be achieved by many approaches.
- Work management will include the consideration of many aspects of worker health and safety than simply radiological protection.

1. NEA (1997), *Work Management in the Nuclear Power Industry*, OECD, Paris.

Current approaches and practices

The focus of a "work management approach" to job planning, implementation and feedback, is on the efficient and effective accomplishment of work. This must be done bearing in mind basic radiological protection principles (e.g. time, distance, shielding, source-term reduction), but work management will generally not be driven by radiological concerns. Rather, a good work-management approach will:

- assure that workers are well trained in radiological protection basics;
- assure that radiological engineers are involved in work planning discussions from the earliest stages;
- facilitate the use of worker experience in defining the processes and approaches that will be used to accomplish the job at hand;
- assure that workers used for a particular job are well trained to perform the job, and have sufficient job skills to work efficiently and effectively; and
- effectively collect post-job experience feedback so that repetitive jobs can be more efficiently performed the next time.

This can be considered as part of the optimisation of radiological protection, in that more efficient work will lead to lower worker doses. Another important aspect of optimisation in the context of work management is that all those involved should be well aware of their roles and responsibilities. The responsibility for final decisions regarding work rests with facility management. Contractors and staff workers are responsible for working responsibly, for knowing and following facility safety rules, and for co-operating with facility management at all stages of the work (planning, implementation, feedback) to provide their valuable experience and know-how. Regulatory authorities are responsible for clearly establishing the regulatory framework for safe work, and for establishing guidance and criteria against which the adequacy of work will be judged.

This structured approach to the management of work and worker empowerment has been very successfully applied in many countries. For example, over the past ten years the average capacity factor for nuclear power plants in the United States has increased from 82% to 92%, and doses were reduced by approximately 50%, through the efficient use of workforce knowledge and work management approaches.

The evolution of ICRP recommendations

The involvement of stakeholders, particularly the workforce, in radiological protection decision making is an important part of the optimisation concept that is currently being developed by the ICRP for its new recommendations. It is likely that this will be addressed only in general terms, but will likely emphasise that input should be appropriately taken into account from relevant sources.

This may challenge regulators to view existing ALARA programmes and optimisation processes at nuclear facilities from a broader, work-management perspective. Keeping in mind the roles and responsibilities mentioned previously, it will be important that an appropriate understanding is achieved between workers, management and regulatory authorities. To achieve this balance, it is useful to recognise the importance of the following aspects:

- the distribution of responsibilities of all involved bodies, such as facility management, workers and the regulator, in decision-making processes;

- the role of work management in worker empowerment, with its primary focus on efficient work as a mechanism to achieve efficient dose management; and

- the need for flexibility in order to most appropriately identify and implement case-specific approaches.

Along these same lines, guidance regarding elements to consider when evaluating the effectiveness of optimisation would be of great, practical use.

5. THE USE OF TOOLS IN OPTIMISATION

Nuclear utilities currently use a variety of “tools”, both quantitative and qualitative, in the process of optimising worker and public exposures. In this context, tools refers to such quantitative things as dose models, pathway analyses, time and motion studies, the use of an “alpha-value”, analyses of past work, or analyses of dose trends. Qualitative tools traditionally refer to such things as engineering judgement, and the use of planning and scheduling to reduce exposures, but are increasingly including discussions and consultations with stakeholders.

While these tools continue to be central to optimisation at nuclear power plants, clarification of ICRP recommendations relevant to optimisation, and increased integration of stakeholder involvement are two areas where the application of optimisation tools is evolving.

Key messages

- The application of a generic level, on the order of a few 10s of μSv/a, below which the need for regulatory control, if any, would be reduced, would be welcomed by the nuclear industry.

- The optimisation process is inherently judgmental and case-by-case, using quantitative and qualitative approaches. As such, flexibility in guidance for the application of optimisation is needed.

Current approaches and practices

Before beginning the optimisation of a task or job, the first step is to decide whether or not the task or job is justified and should be performed. At a nuclear power plant, work is driven by many motivations, including nuclear safety, plant upgrade, plant backfit, environmental pressure, regulatory authority pressure, dose reduction, etc. In evaluating whether a job is needed or simply “nice but not necessary”[1] many of the above-mentioned motivations may be considered. This being said, it is true that work that is not performed gives no dose and does not need to be optimised.

One aspect of work justification that has always been somewhat difficult to address is that of risk transfers. Plant modifications undertaken for nuclear safety reasons, or to reduce emissions for public or environmental protection, are, in effect, transferring risk from the public and the environment to workers, in the form of the worker exposure needed to perform the work. However, the ICRP has never provided guidance with regard to the types of considerations that should be balanced in making such judgements. Such considerations are equally related to the justification of the work and to the optimisation of the work that is going to be performed.

Once a job has been justified, however, radiological protection must be optimised. Many computer-aided tools have been developed to assist work planners in the optimisation of radiological protection. As computing technology has improved, so have tools and their human interfaces. The use of such things as video-tours, dynamic computer-graphic models of work areas, and gamma spectrometer dose rate maps have made it possible for planners to study the efficiency of various protection options efficiently, cheaply and without the expenditure of dose. Such tools will continue to evolve and to assist job planners in their work of optimisation. Examples of several approaches to optimisation are provided in Appendix 6.

In parallel with the evolution of quantitative tools, has been an evolution in the approach to the management of radiological risks. Increasingly, optimisation processes include some level of stakeholder input. As the concept of stakeholder involvement in decision making has become increasingly accepted, the role of radiological protection within the decision-making process has evolved. This has lead to a better understanding of roles in decision making, but has also highlighted a few areas where further ICRP guidance would be of use.

For example, in some countries and for some situations, more than one national authority may be involved in the approval of work. Authorities responsible for nuclear safety, radiological protection, or environmental protection may each have input to certain decisions, and may each have certain approval authority. Under these circumstances, coming to agreement on the optimum approach to radiological protection is not obvious, and again, guidance on the balancing of various aspects of nuclear safety risks, environmental protection, public protection and worker protection would be of great use.

Work efficiency is also an area of high concern to nuclear power plant operators, such that work management is often a key issue in job-related decisions that might affect worker exposures. For example, such considerations may push plant management to early decisions regarding the need for and approaches to a particular job. Such a framework inherently limits the ability to optimise radiological protection. To help in such situations, it would be useful if the ICRP were to reiterate the importance of radiological protection considerations being taken into account from the very earliest phases of job planning.

In the context of stakeholder involvement, an important aspect of the optimisation process is that it ends when the optimum solution is identified and agreed on by stakeholders. Remembering that optimisation is not a process of minimisation, but a process of effective dose management, there is broad support within the nuclear industry for the definition of a pre-defined level of dose below which optimisation is no longer needed. Such a value, 10 μSv for public exposure for example, would need to be agreed upon by regulatory authorities and utilities, and would also benefit from international support from the ICRP. Exposures below this level could be considered "safe".

The evolution of ICRP recommendations

The latest draft recommendation material from the ICRP seems to address some, but not all of these concerns. For example, the Commission's objective to clearly define such terms as dose limits and dose constraints, and to establish a "lower boundary" constraint at 10 μSv, would be welcomed by the nuclear industry. However, guidance in the areas of risk transfers and in the use of justification is still needed.

6. ALARA IN OLD PLANTS *VERSUS* ALARA IN NEW PLANTS: ARE THEY EQUAL?

Regulatory authorities often compare the results of one nuclear power plant with those of another. In the case that the plants being compared are identical, or at least very similar, valid comparisons can be made. Valid comparisons can also be made, to a point, of similar jobs being performed at different plants. However, comparisons are also made of plants that are not similar, for example, a very old plant compared to a very new plant. For both plants, the regulator will require that exposures (worker and public) are maintained ALARA. However, the optimisation process at one plant may result in very different levels of exposure.

Under these circumstances, it is important to have criteria to demonstrate that exposures are ALARA, regardless of their absolute level as long as individual doses are below dose limits. In such a context, operators may be concerned with the operational aspects of demonstrating that ALARA in an older nuclear power plant is as "good" as ALARA in a newer nuclear power plant.

Key messages

- Optimisation of dose, below a given dose constraint, focuses on the process, not on the results. As such, the site-specific philosophy for the implementation of optimisation and the ALARA philosophy may be equivalent while yielding different results.

- It would be very useful to have guidance on the types of criteria that should be considered when judging the effectiveness of an ALARA/ optimisation programme.

Current approaches and practices

The commercial nuclear power industry began in the 1950s and 1960s, and since that time several hundred commercial nuclear power plants have been designed and built. Over 400 are still operating today. As such, it is not surprising that individual units can be significantly physically different, one from the other.

The current fleet of commercial nuclear power plants consists of five distinct and different designs; PWRs, BWRs, CANDU and RBMK reactors, and gas cooled reactors. Within each type of design, advances over the years in engineering systems, command and control approaches, materials properties, etc. have lead to significant design differences from one generation of plant design to the next. Many different approaches to plant design have been tested. All this to say that there are significant physical differences between plants, and these differences can have a significant effect on operation and maintenance/ refuelling outage exposures.

Another factor that can significantly affect plant worker doses is operating history. Some plants have leaking fuel incidents. Some plants have a water-chemistry history that has not effectively prevented the build-up of pipe scales (which are often a significant source of occupational exposure), such that ambient dose rates in work areas, and thus worker doses, can be much higher than those at another, perhaps even identical plant.

For these reasons, it is not simple, and often not valid, to compare the absolute, numerical values of worker doses from one plant with those of another. Appendix 6 provides a good case study example of these difficulties. In this same context, it should be noted that an ALARA programme can be affected by decisions beyond those addressing specific radiological protection issues. For example, management decisions regarding schedules and priorities may have significant effects on occupational exposures, and should thus be considered with the ALARA philosophy in mind.

While worker exposure results can be one indicator of the effectiveness of a plant's dose management programme, often called the ALARA programme, these can not be the only criteria used to judge a programme's effectiveness. Keeping exposures ALARA is first and foremost a way of thinking, rather than a formula. The need to manage worker exposures is universal, but the approaches taken and the results achieved will depend upon the case under consideration. Worker dose trends are important, worker attitudes are important, plant management attitudes are important, sufficient resources must be allocated to achieve exposures that are ALARA. But as has been previously discussed, stakeholder involvement and worker empowerment are necessary to achieve doses that are ALARA, and thus this process is, *de facto*, subjective and judgmental.

While this does not free nuclear power plant operators from numerical regulatory criteria, it should indicate that the ALARA process is, at the very least, as important as the dose results that are achieved. For regulators, however, this makes the quality of a plant's ALARA programme more difficult to judge. Various criteria are used, including dose results, dose trends (site dose, outage dose, task dose, etc.), plant cleanliness, or the number and severity of rule and procedure violations (personnel contamination, controlled zone entry violations, etc.). These are all useful tools to assist the operator and the regulator to judge the effectiveness of an ALARA programme. However, there is no clear international guidance as to the types of criteria that should be used to judge ALARA programme effectiveness.

The evolution of ICRP recommendations

The early draft versions of the new ICRP recommendations favoured replacing ALARA with the notion of optimisation of protection to achieve the best level of protection available under the prevailing circumstances. Since these early ICRP drafts, stakeholder input has clearly indicated that ALARA is now so deeply part of the radiological protection philosophy it would be a mistake to abandon this concept. It thus appears that the ICRP will keep the philosophy of ALARA in its new recommendations.

However, there is still a need for some level of international harmonisation of understanding on what criteria, or types of criteria should be used to judge the effectiveness of an ALARA programme. The development of such criteria would be of use to regulators and operators alike. While these should not be prescriptive, they should be clear.

7. OPTIMISATION OF DECOMMISSIONING

As more and more nuclear power plants around the world approach, or have entered, their decommissioning phase, regulatory interest in decommissioning has risen. Key aspects of decommissioning are the optimisation of worker exposures, and of public and environmental impacts. Optimisation is important in choosing the length of the "safe-store" period when defining a decommissioning strategy, is important in determining how much remote and/or semi-remote work is to be performed as opposed to hands-on work, and is a significant criteria in the selection of other aspects of decommissioning strategy. The application of national policy is another area where optimisation is important, for example in the optimisation of residual levels of contamination, below nationally-established constraints, and thus of residual public exposures.

As many nuclear installations will soon be, or are beginning to optimise their decommissioning strategy, they will be considering options, and determining how to demonstrate to their regulatory authorities that their strategy will result in worker exposures that are ALARA.

Key messages

- Any levels that are eventually chosen for clearance levels, and regulatory requirements for release measurements for verification of compliance with these criteria should not result in excessive worker exposures.

- Worker exposures should be key elements that are considered when national decommissioning policy is developed.

Current approaches and practices

The identification of the important aspects of optimisation of decommissioning activities is only in its early phases, partly because decommissioning policy in many countries is still in its early phases. For example, no country in the world today has operational waste disposal facilities for all the classes of waste that will be generated by decommissioning activities. There is no international agreement on the radiological specific activity levels below which international trade in commodities should be allowed without regulation based on radiological considerations. There is much international discussion regarding decommissioning regulations, but many countries are still considering whether to develop specific regulations regarding decommissioning, or simply to apply as appropriate their existing regulations interpreted for decommissioning.

As such, many of the elements that would be necessary to perform complete optimisation studies are not yet in place. This does not mean, however, that work is not actively ongoing in industry to develop strategies for decommissioning. These strategies are generally driven by costs, but they must fit within the framework of national policy that may or may not be complete.[2] The strategies that nuclear installation operators will submit to regulatory authorities for approval include such aspects as time-frame (i.e. delayed or immediate dismantling), end use of the site following decommissioning (i.e. green field, continued use as nuclear site, continued use as industrial site), the scope of the decommissioning project (i.e. including final waste management aspects or not, including all facilities on site or not), waste conditioning approaches (small packages, large packages), etc.

Specifically, many aspects of national policy and regulation may be important to the optimisation of radiological protection for decommissioning. These include:

- **Waste conditioning requirements**: the allowable size of waste packages will have a bearing on the cost of their preparation and packaging, and on worker doses.

- **Material release requirements**: the radiological criteria for releasing material for unrestricted use (i.e. release measurements, radionuclide scaling factors, surface and volume contamination criteria) will influence decisions to decontaminate material and to segregate materials, both of which will have an influence on worker doses.

- **Site release requirements**: in optimising decommissioning, the cost of reducing public exposures will be important. The level at which national regulators fix radiological criteria for site release will have a significant effect on these costs.

2. NEA (2003), *Decommissioning Nuclear Power Pants; Policies, Strategies, Costs*. OECD, Paris.

- **Safe-store requirements**: many decommissioning strategies include some time-period of safe-store for various facility buildings (reactor building, fuel storage building, turbine halls in BWRs, etc.). Surveillance requirements for these periods will affect worker exposures.

Decommissioners have the tools that are needed to effectively optimise their activities within the frameworks of national policy and regulation. National policy and regulation in these areas will, however, be affected by the choices made by the ICRP.

The evolution of ICRP recommendations

Although decommissioning is not directly addressed by current discussions of the new ICRP recommendations, several issues that are being discussed are fundamental. In particular, the choice of dose constraints will have a significant effect on the framework within which decommissioning activities must take place.

For example, as previously discussed, the use of a rigid 20 mSv per year worker dose constraint would be less flexible than the current approach to worker dose limits as presented in ICRP Publication 60. Sufficient flexibility to effectively optimise in specific cases would be useful in this context. Similarly, a dose constraint of 0.3 mSv per year that would apply to public dose, particularly for the release of sites and facilities, seems to be operationally fairly low, particularly for certain radionuclides that become very operationally difficult to detect at this dose level.

8. INTERNATIONAL ASPECTS OF OPTIMISATION

Inherently, the ICRP strives for some level of harmonisation and common understanding in issuing its international recommendations. In operational radiological protection, the need for common approaches and understanding appears in many areas, but has been particularly felt in terms of the use of "international" workers, "itinerant" workers, and the use of "equipment" brought from abroad by international teams.

In terms of workers, regulatory problems can arise when, for example, workers from a country with a 50 mSv/a worker exposure limit have travelled to countries with a 20 mSv/a worker exposure limit, or visa versa. In practice, such situations are addressed by various operational approaches (e.g. worker exposure constraints in contracts, or maintaining workers below the applicable limits for the work they are performing). These approaches are, however, case by case and generally not co-ordinated.

The related issue of the so-called itinerant worker also arises, mostly at the national level, but increasingly at the international level. Itinerant workers are those who receive doses in more than one facility during the year, maybe in more than one country. How their radiological protection should be optimised has for some time been a philosophical and practical problem for regulators and implementers of radiological protection. Optimisation is complex in this case because the "sources" of exposure (for example, several nuclear power plants) may be controlled by different organisations and optimisation processes.

In practice, workers arriving at a work site carry some sort of national and/or international "authorised dose report", and nuclear facilities optimise the worker's exposure at THEIR facility. The questions of practical importance then become:

- How can the overall radiological protection for an individual worker's be optimised?
- How is responsibility shared for this optimisation?

- How can it be demonstrated that the radiological protection for a worker is optimised?

A corollary to these situations concerns the specialised equipment that international workers may bring with them. In certain cases, equipment that has been radiologically released from a controlled zone in one country may still have contamination levels that are higher than those accepted in another country. As such, equipment **entering** a controlled area may be stopped, and detailed and expensive follow-up studies may need to be initiated to perform radiological surveys of the pathway followed by the "contaminated" equipment.

Several practical approaches to managing the exposures of itinerant workers have evolved and will be addressed in this section.

Key messages

- The level of common approaches and understanding needed to effectively optimise radiological protection for the public and worker needs to be discussed.

- The responsibility for the management of worker doses and the optimisation of worker radiological protection lies at all levels:

  – the management of worker doses and the optimisation of worker protection is the responsibility of the worker's employer; however

  – the facility causing worker exposure is responsible for optimising protection against all doses received at that facility;

  – national regulatory authorities are responsible for reviewing worker doses and their compliance with dose limits.

- Expanding the use of practical tools, such as "dose passports", should be explored nationally and internationally.

Current approaches and practices

The globalisation of the commercial nuclear power industry is increasingly leading to specialist teams performing work in many different countries. In situations where national radiological protection regulations differ from country to country, this can cause confusion.

It is clear that the rules and regulations at the location where the work is taking place will take precedence, should these be different than those in the home country or facility of the worker. However, differences may well exist that would leave workers in ambiguous situations. The most obvious situation is when national worker exposures limits are different. For example, some countries apply 100 mSv 5 years with 50 mSv the maximum allowed in any one year. Some countries simply apply 20 mSv per year, although this may be over a calendar year or a sliding 12 month scale. The United States applies the older ICRP 26 limit of 50 mSv per year. As previously mentioned, this not only causes problems with the optimisation of a worker's protection over the course of the year, but may also cause confusion in local regulatory requirements.

Such situations would benefit from a broader international discussion of regulatory approaches. At the very least, increased communication of regulatory and procedural approaches internationally would facilitate the case-by-case addressing of these situations.

In terms of the management of worker exposures, responsibilities are split. In the legislation of most countries, the employer is responsible for maintaining the worker's total work dose ALARA. The facility causing the exposure is generally responsible for assuring that all doses received at the facility are ALARA. For workers employed by the facility causing the dose, the two responsibilities lie with the same employing organisation. However for contractors, who receive much of the exposure during nuclear power plant refuelling outages and who may work at several refuelling outages per year, the management of exposures can be more complicated. The employer must manage the worker's dose through a series of optimised tasks at different plants, and must also manage the worker's total annual dose, and demonstrate the optimisation of protection to regulatory authorities. Nuclear power plants are obliged to optimise worker protection from doses received at the plant. In doing so, they take into account the worker's dose history, as reported on some sort of nationally-recognised authorised dose report.

In practice, various approaches are used. The focus of optimisation is generally at the local and job level. This concerns the radiological protection management at the plant, the contractor's radiological protection management, and the worker. Working together on the task at hand, the optimisation of protection is discussed and agreed upon. The formalism necessary for this process will vary from plant to plant, but will generally depend upon the level of dose that is expected. The higher the dose rate in the work area, and/or the higher the level of individual dose estimated for the work, the more formal the process of radiological protection option analysis.

A key tool in this analysis is the worker's past dose history. Many different forms of "authorised dose reports" are used, including written and electronic versions. In general, a plant is obliged to furnish each leaving worker with such dose information, and plants refuse entry to workers who do not present such information upon arrival. Electronic worker dose databases exist at the national level in many countries, however most international worker exchanges are accomplished using written "dose passports" in some form that is recognised by participating countries. It should be noted that such systems are increasingly being used for the transfer of other information from plant to plant. This can include training records, worker certifications or licenses, or even medical records. The legal obligations associated with the recording and viewing of information that may be legally treated as personal and/or confidential will vary from country to country. It should be noted that the unambiguous identification of individuals in electronic databases can sometimes become problematic as a result of legal restrictions on the type of information that may be recorded, thus sometimes posing practical problems for operators and regulators alike.

Another approach to optimisation that has been applied by power plant operators involves the use of worker dose criteria in work contracts. To assure that contract workers do not approach regulatory limits while working at their plants, some operators impose contractual dose restrictions on incoming workers. Operators may also include, contractually, the right to review the overall radiological protection training, plans and objectives of their contractors to further assure that workers are appropriately radiologically qualified to perform work in radiologically controlled areas.

One source of confusion in this process has been the different local and national interpretations of ICRP recommendations regarding the time period applicable for worker dose limits. The ICRP Publication 60 recommendation states in paragraph 166:

> *The Commission recommends a limit on effective dose of 20 mSv per year, averaged over 5 years (100 mSv in 5 years), with the further provision that the effective dose should not exceed 50 mSv in any single year. The 5-year period would have to be defined by the regulatory agency, e.g. as discrete 5-year calendar periods. The Commission would not expect the period to be introduced and then applied retrospectively. It is implicit in these recommended dose limits that the dose constraint for optimisation should not exceed 20 mSv in a year.*

From this statement, it is not clear whether the 5-year and 1-year periods referred to are calendar years or sliding 60-month and 12-month periods respectively. As such, it is somewhat difficult to manage optimisation of exposures in a uniform fashion.

There has also been a desire, from regulatory authorities and nuclear power plant operators, that the concepts of dose limits and dose constraints be extremely clearly defined and explained in any new ICRP recommendations. A clear understanding of these concepts is essential to the development of a manageable approach to optimisation of worker doses, particularly itinerant workers.

The evolution of ICRP recommendations

In developing its new draft recommendations, the ICRP has worked to achieve broad agreement on its approaches, and thus broad acceptance of its recommendations following their publication. The hope would thus be that at least the philosophy of the new ICRP recommendations would be universally adopted, and hopefully also the more specific aspects of the recommendations.

Even if this is achieved, however, various radiological protection regulations will remain country-specific. To address this situation, it is strongly suggested that regulators discuss such situations more actively among themselves, and attempt to highlight such situations at the international level as they arise.

In order to best facilitate the work of regulators and nuclear power plant operators, the ICRP should bear in mind that its new recommendations should be clear, but should not reduce the flexibility needed to address specific national and local circumstances.

In terms of the management of worker exposures, although the globalisation of the workforce is putting pressure on the nuclear industry and on national nuclear regulatory authorities to increasingly harmonise and co-ordinate, national and local differences in approaches will continue to exist. In developing its new recommendations, the ICRP should bear these differences in mind, such that new restrictions are not imposed on existing national practices that have been evolved, pragmatically over time, to address identified needs. Specifically with regard to dose itinerant workers, it would be most helpful if the ICRP would more clearly define what it means by dose constraints and dose limits, should these concepts be retained. The definitions should bear in mind that these concepts will certainly be used in a regulatory context, such that the consequences of exceed numerical values in each case should be considered, if not explicitly discussed.

In terms of the time periods over which limits and constraints should be applied, the ICRP should describe the rationale behind the time periods it selects for limits and constraints, rather than taking a very prescriptive approach. From this, national regulators should be encouraged to develop, as appropriate among themselves, practical approaches that address the spirit of the Commission's recommendations, and that allow national solutions to function while moving towards closer harmonisation, as appropriate.

9. CONCLUSIONS AND RECOMMENDATIONS FOR FUTURE WORK

The ISOE programme is made up of a very broad constituency of utilities and regulators organisations, and has throughout its existence worked to exchange information and experience among its participants to facilitate the efficient and effective management of worker exposures. This report reflects the current practice of this broad group, particularly in the area of optimisation, and thus to a certain extent represents common views of how optimisation is implemented in the field. This view has been driven by existing international recommendations, national policies and regulations, and operational experience. Suggested improvements to international recommendations that could affect the application of optimisation are thus always welcome, but are expected to filter their way through tests against current policy, regulation and application where they should demonstrate their value before passing further.

In this sense, this report presents the ISOE view of current practice in optimisation, reflects on how changes proposed by the ICRP could facilitate the application of optimisation, and suggests what further reflection, guidance and clarification by the ICRP would be useful before new recommendations are finalised. Justifiable changes, based on science, and clear guidance providing a framework for operational application of radiological protection in a necessarily flexible fashion would be welcomed by the participants in the ISOE programme.

Along with the NEA Committee on Radiation Protection and Public Health (CRPPH), the ISOE programme will continue to follow the evolution of the system of radiological protection, and the finalisation of the new ICRP recommendations. It is recommended that, once the new recommendations are published, the ISOE programme could assess, after sufficient time has passed, to allow better operational understanding of the recommendations, the implications that the new recommendations will or could have on the operational aspects of radiological protection, in particular the optimisation process. This valuable feedback could then be provided to the NEA and the IAEA (the two co-sponsors of the ISOE programme) for their regulatory and statutory consideration, and to the ICRP for its further consideration of clarification guidance.

Appendix 1

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Appendix 2

Examples of Optimisation of Public Exposure from Effluent Releases

Optimising exposures from the Ignalina NPP, Lithuania

To ensure safety for the general public from the operation of nuclear installations, international recommendations and national radiation protection regulations require licensed facilities to control the transfer of radioactive substances from their controlled areas to the environment. The responsibility for commencement of this type of regulations lies normally on the governmental level, but the regulations should be conformed to the international requirements because of the global nature of radioactive contamination.

There is an obligation for the operators to establish radiation protection policies and arrangements to protect the general public and the environment. It should contain both measures to control the radioactive releases to the environment and to perform monitoring of the environment in purpose to assess doses to the critical group of the general public.

Protection of the general public and environment from external radiation and radioactive contamination should be a condition considered in planning of a new practice dealing with radiation sources.

An important step in optimisation is to ensure that the operators, in order not to exceed the values of dose constraints, are implementing appropriate technical and organisational measures that are necessary for ensuring the protection of the public in relation to the radioactive discharges for which they are authorised (for example, performing effluent monitoring (by setting up the necessary frequency of radionuclide measurements, detection limits in the releases), implementing environmental monitoring programme, etc.). In order to demonstrate the compliance with the public dose constraint, the operator has also to prove to regulatory authorities that the discharges are kept "as low as reasonably achievable" (ALARA).

An example of the critical group selected for the calculation of maximum permissible discharge limits in Lithuania from the operation of Ignalina NPP is given below.

Site specific assessment has been performed. The composition of the members of the critical group and dose conversion factors in the vicinity of Ignalina NPP were investigated. It has been found that the critical group exposed from the water effluents of radioactive substances are the fishermen fishing in Lake Druksiai, which is used for cooling of reactors, and that farmers residing in the vicinity of the plant are most exposed to the air releases. Dose conversion factors to the critical group (Sv/Bq) were then calculated using modelling studies.

In many practical cases, the annual dose constraints set by the regulatory authorities, are equal or below the default value for a source related dose constraint of 0.3 mSv recommended by the ICRP (for the case of Lithuania it is 0.2 mSv per year). The discharged radionuclide activities are contributing to the annual dose constraint not more than to few percentage points (an example of Ignalina NPP).

Effluent optimisation approaches in the United States

Doses

Environmental doses from nuclear power plants are estimated using a number of methods and sources. Atmospheric or liquid releases of radioactivity are measured before or during release. Environmental pathway models are used to estimate the probable upper bound of dose to any worst-case individual from those effluents. Additionally, environmental sampling programmes compare the activity actually in the environment to background and calculations of effluent to confirm that effluents are as reported.

Direct radiation

Direct radiation is measured using fixed self reading devices (e.g. pressurised ion chamber – PICs) and with long-term integrating devices that are evaluated periodically (e.g. TLDs). Direct radiation reading devices will indicate both the direct shine from radiation sources in the plant and from gamma emitters in plumes and deposition from effluents. Background references are established at a greater distance (typically greater than 10 miles) than would be expected to routinely have direct radiation impacts. There is no separate regulatory requirement limiting direct radiation other than the overall sum limits. Impact to the public is assessed based on net changes in readings at a monitoring site and a supposed residence time for individuals. An elevated result at the plant site boundary with no human residence would have a reasonable duration selected for public exposure. For example, if at a shoreline, the value for shoreline exposure from the liquid pathway might be used.

Measurements of changes in direct radiation are not precise. PICs will indicate changes in ambient dose rates for many reasons. Rain events will wash out natural radioactivity (e.g. ^{7}Be) and cause an increase in indicated dose rate. Snow cover will decrease dose rates. Inversions can increase dose rates due to reduction in diffusion of radon. Similarly, there are overall seasonal changes. Integrating devices are subject to variability due to calibration inaccuracies between devices used in consecutive monitoring periods. Long-term changes such as seasonal differences are obvious in long-term trending of TLD data. Individual sites vary significantly from each other due to environmental conditions, geology at the site, and surface condition. Changes can occur without monitoring staff knowledge. For example, paving a dirt access road will significantly change TLD results.

Given a long-term monitoring effort, duplicate devices at each monitoring location, and good preoperational as well as stable operational data collection, TLD monitoring may be able to detect on the order of 3 mrem/qtr above background during a quarterly monitoring period. PICs can readily detect short-term transients on the order of a few μR/hr with effort, but are limited for population monitoring by the high cost and therefore few monitoring locations.

Effluent measurement

Effluents are measured on a time weighted average basis. Samples of effluent streams are collected in a variety of ways that contribute to more or less time averaging. USNRC regulatory guide 1.112 discusses the basic expectations of information needed to develop source term data for power reactors but does not provide specific monitoring requirements. The branch technical position on effluent tech specs and standard effluent tech specs provide fundamental isotope and monitoring/sampling requirements. However, compliance with the branch positions and standard technical specifications is not mandatory.

At a PWR, a waste gas decay tank will be sampled after a specified hold-up time, and then released. However, the release of a WGDT will occur over a period of several hours.

Meteorological conditions will vary over that time period, and the actual mass flow may vary with time as pressure decreases. On the other hand, the condensate leakage releases from a PWR, which will contain some plant-related activity due to the unavoidable though minute primary-to-secondary leakage, is completely different. Turbine building sumps will be pumped automatically with volumes totalised. Periodic samples are applied to the entire totalised volume, and treated as a continuous release, even though there will be periodic pump start and stops. Normal plant HVAC is side-stream sampled, with samples collected typically on a weekly basis. However, these samples may be either continuous collection or short duration grab samples depending on the element and media.

Typical analyses of effluents for a PWR can be summarised. Gaseous effluents typically consist of WGDT releases and normal HVAC. WGD tanks will be recirculated and sampled for about 15 noble gases using a gas volume sample, 5 radioiodines using a charcoal or AgZeolite media, and “typical” fission and activation product gamma emitters using a thin filter. Tritium as tritiated water may be sampled using a drying column or bubbler. The thin filter may be subsequently digested and composited over some fixed time period (e.g. monthly or quarterly) for gross alpha activity and $^{90}Sr/^{90}Y$.

HVAC and condenser off-gas flow is sampled and monitored. Gross gas detectors measure a volume of side-stream flow for gross noble gas activity. This is normally calibrated based on a primary isotope of interest. However, this mix can change depending on fuel condition and hold-up time in the buildings. Radioiodines are sampled with continuous flow cartridges, typical collection times are one week. Particulates are also collected using side-stream filter samples, typically collected for one week. Decay over the time period is accounted for, but time-dependent variations in the mix (e.g. small short-term leak of less held-up activity) cannot be. Tritium is sampled by side-stream, either by continuous sampling or grab sampling.

Liquids are monitored by individual sampling of tanks released, and grab sampling of turbine building sump discharges. Gamma analyses, tritium are conducted on the samples, and composites are made for other isotopes, such as gross alpha or $^{90}Sr/^{90}Y$.

At BWRs the effluent monitoring is somewhat different reflecting the differences in design. Condenser offgas is the primary source of atmospheric releases. Such releases are normally processed through a holdup/filtration system to reduce the quantity of radioiodines and short-lived noble gases. Because of the continuous nature of these releases, sampling is periodic to establish mixture ratios and conversion factors of continuous gas monitors in the combined HVAC, offgas stream. Side stream iodine and tritium is also collected. As with PWRs, tritium collection may be periodic grab sampling. Liquid effluent sampling and analysis is similar as for PWRs. Due to the condenser off-gas process in BWRs with treatment system, the isotopic mix can vary considerably with time. Changes in power level will change the short to long half life ratios, changes in control rod position can change the amount of short-lived noble gases released, and the offgas treatment system can "trip" resulting in changes in isotopic ratios for the period when the system is off-line.

Both PWRs and BWRs therefore, routinely sample and monitor for the common fission and activation products. The effluent quantification is typically time weighted averaged over periods of days to months, depending on the release path, sample media, and isotope. Plant-specific "technical specifications" which are part of the unit license define the sampling requirements for isotopics and periodicity. Methods of collection and analysis are determined by plant staff and subject to review by regulatory inspectors. Effluents are summarised annually and reported to NRC consistent with the guidance in RG 1.21.

Effluent limits

Effluents are limited by the plant license in two ways. Maximum release rates of certain isotopes (particularly the noble gases) (Ci/sec) are delineated. In addition, specific limits to dose commitment rate (mrem/hr to a receptor) and total dose commitment are specified. The dose commitment limits are generally based on three sources, 10CFR20 public dose limits from the NRC, 10CFR50 Appendix I from the design goals for licensing of commercial power plants from the NRC, and 40CFR190 from the EPA public dose limits. The use of the overlapping limits (max curie rate, max dose rate, max dose) provides for operational flexibility and allows accounting for actual dispersion in the environment.

The 10CFR20 dose limit to a member of the public is based on the existing ICRP guidance. The 10CFR50 App. I guidelines implemented into most plant specifications are design criteria. 10CFR50 App. I specifies that plants be designed in order to achieve effluent doses less than those specified, and that those guidelines are considered to be sufficiently ALARA for public protection and design constraints. The 40CFR190 limit is based on a limiting risk to the public using existing risk factors. Interestingly, this limit (which is lower than the ICRP public dose guidance) only applies to the nuclear fuel cycle and dose not apply to other users of radioactive material and radiation.

Dose limits typically implemented in nuclear plant technical specifications:

10CFR20	100 mrem to a member of the public
10CFR50 App. I	liquid – 3 mrem total body, 10 mrem limiting organ gaseous – 15 mrem any organ from iodines and particulates 5 total body, 15 skin noble gas
40CFR190	all sources – 25 whole body, 75 thyroid

Note that the 10CFR50 and 40CFR190 limits are still based on individual organ limits from ICRP2 methodology.

These limitations are implemented as a limit to any single individual, normally referred to as the "hypothetical maximally exposed individual". Therefore, the typical dose to individuals in the local resident population would be less than that to the limiting person. In the United States, there are no population dose limits on operating nuclear power stations.

Dose modelling

Liquid and gaseous effluent doses from US nuclear power stations are calculated using a variety of methods. These vary in the degree that site specific data is used, in the source and granularity of the dispersion data, and the extent that the receptors are loaded into a three dimensional description of the environment.

The nuclear regulatory commission has provided licensees with several regulatory guidance documents that describe acceptable effluent dose assessment programmes. RG 1.111 provides basic models for atmospheric dispersion calculation for different release modes, as well as fundamental dispersion parameters. RG 1.113 provides similar information for liquid effluent dispersion. These are collated and condensed, along with other environmental parameters into RG 1.109, which is the fundamental regulatory guidance document for effluent dose assessment from the release point to dose to the public. The regulator compares the recommendations of basic calculations in RG 1.109, along with the actual results obtained with a standard model, to the model and results obtained by the licensee to determine if release calculations are within expected guidance. Other documents that are fundamental to modern effluent analyses at US nuclear power stations are NUREG CR/3332 **Radiological Assessment** and **Meteorology and Atomic Energy**. Both of these references provide additional clues on dispersion assessment and environmental modelling.

There are several basic elements to the effluent dose calculation process. These include a dispersion model, a transfer model, dose conversion factors, and a biosphere simulation. The dispersion models vary significantly in detail. The model must first represent the effluent release point.

For atmospheric releases, depending on the height above the ground or surrounding structures, a release point may be considered ground, elevated or a mixed combination of the two. Units may have multiple release points that are modelled differently. For simplicity, release points may be treated as a ground level release even though they may have some mixed wake character. The amount of plume rise resulting from the exit mechanical flow may or may not be accounted for. In those cases where plume rise is considered, different references provide multiple examples of usable plume rise equations. Plume rise will be dependent on the width of the plume, the linear flow rate and the temperature difference with the atmosphere. For any given release point, at least the latter two will vary depending on the day-to-day operation of the plant and the outside air temperature. Precise modelling of this impact is not included in routine models.

Building wake effects are typically included in the models, but wake turbulence and building wake mixing will vary with wind direction. The effect of varying wind direction on wake mixing is not precisely accounted for.

Most units use a straight-line gaussian dispersion plume model based on the pasquill stability classes and tables from RG 1.111. Some may use a more discrete model using variable trajectory to account for spatial changes in wind fields. This is more likely when units have known local factors such as a prominent valley flow. However, the discrete models are dependent on multiple wind field data sets for accuracy. Additionally, the straight-line gaussian plume may be modified with a recirculation factor to provide a simplifying compensation for variable wind fields.

The use of the straight-line gaussian model is, by its nature, an averaging process. Since the plume meander averaged out into the gaussian distribution is time dependent, downwind concentrations for short releases may be less accurately represented in a gaussian plume. Even the method of application of the gaussian plume varies between stations. Most units are required to match the meteorological conditions that existed during the release to the release time to include in the dose model. Therefore, data obtained from an on-site met tower is input into the model on a time dependent basis, matched to the release times, and specific dispersion calculations are made to each met data element in each release period. However, some units do not have that requirement. They have a long-term average dispersion parameter derived from a few years of historical met data. This single historical dispersion parameter is applied to all releases. No attempt is made to account for specific met conditions or even the specific wind direction at the time of the release. A dispersion model may use the narrow dimensions of the gaussian plume, or may apply the vertical dispersion only and use the width of a compass sector for the horizontal dimension of the plume. Surface roughness is unlikely to be accounted for but changes in terrain height, which affect the vertical dispersion, are likely to be included. Transient atmospheric conditions are also unlikely to be modelled. The capping effect of strong lofted inversions for example is not considered in these simple models.

The transfer model is used to account for the movement of the radioactive material through the biosphere. This will include the chemical behaviour of each element as it enters, interacts in, and travels though the biosphere/food chain. There are a number of these factors:

The behaviour of the element as it first interacts with soil it deposits on, or on vegetation it first deposits on:

- how this initial deposit washes off or runs off;
- how it then binds to soil;
- how it is then taken up by vegetation through root absorption;
- quantities of vegetation eaten directly by humans, on an individual and population basis, amount of washing of food stuffs before use;
- amount of fresh vegetation eaten by meat or milk animals;
- amount of dried stored vegetation eaten by animals;
- whether the dried vegetation is from the same place as the fresh;
- elemental transfer from the forage to the edible meat or the milk;
- inhalation rates of different age humans;
- consumption rates of different age humans.

All of these parameters and many more grossly affect the results of dose calculation, and in fact the actual doses received. However, in all but a few cases, there is almost no site specific data on any of these parameters. RG 1.109 provides default suggestions based on NRCs review of a wide range of data on each parameter. Since the enviro-biochemical behaviour of elements in effluents is highly dependent on the environmental conditions (soil types, rainfall amounts, etc.) and on the chemical form released actual environmental behaviour of effluent radionuclides will vary widely from location to location, even within the area of the biosphere model of a single plant. For example, values of soil-to-root transfer varies greatly depending on the plant species and the soil type. Extensive specific studies would be needed to assess the specific transfer factor for elements and plant of interest for local soil types. This is typically not dose, and choices are made based on RG 1.109 suggestions or in same cases some literature search for limited cases of specific interest.

The dose conversion factors in use are provided in RG 1.109. These are based on four age groups and are organ and isotope specific. They are from the ICRP 2 methodology. Additional NUREG publications provide factors for more isotopes not included in RG 1.109, but are still of the ICRP2 vintage. These dose conversion factors convert total radionuclide intake to committed dose.

The final significant piece of the dose calculation is the biosphere model. The location of individual “receptors” is identified as a location to calculate dispersion, uptake etc. Licensees identify the location of homes or groups of homes, home gardens of sufficient size to provide a significant fraction of food, major vegetable producers, and milk and meat animal farms to include as receptors in the models. Residence locations are used as the basis for calculation of direct radiation dose from the plume contents, direct radiation from surface deposition, and inhalation dose. Vegetable production locations are used for the vegetable ingestion uptake pathway, as are the locations of the meat and milk production. Vegetables are typically separately treated as leafy vegetables, and fruits and grains, since the leafy vegetables will have different deposition collection tendencies than a fruit or grain. Milk may be cow or goat, meat is typically beef. Although locations of chicken (meat or egg production) may be included in the meat pathway receptor distribution in the model, there is no data provided in the regulatory guidance for chicken or egg transfer factors. RG 1.109 includes recommended ingestion and inhalation rates for the four age groups used for a “maximally exposed individual”. These intake rates are intended to be a reasonable upper bound on the likely usage of a single individual. For example, a teenager is defined to drink 400 litres of milk per year.

A typical dose calculation will have a biosphere model that identifies the closest residence and vegetable garden in each of sixteen compass sectors. If no garden is identified, it may be assumed that the residence has a vegetable garden. If the plant has an elevated plume, the residences or clusters of residences out to five or ten miles may be included in the model. Similarly, gardens will be further identified or assumed, most likely assumed. These residences and clusters are identified by periodic land use surveys and by reviewing high detail maps such as geologic survey quadrangle maps. Large vegetable farms will be included when identified. The land use survey will also identify the location of dairy and meat animal farms within a pre-determined radius of the plant, typically five or ten miles. The locations of each of these receptors are identified in the model by compass sector and distance. These receptors locations are then assumed to apply to all age groups. It is not attempted to keep track of the age of individuals in individual residences. Therefore the dose calculations are done to all four age groups at any residence location since it is not known what the ages of actual residents are.

An additional element of the biosphere simulation is the population distribution. US nuclear power plants are generally not required to provide estimates of total population dose from effluents. However, those that do use varying degrees of accuracy of population distribution. Population dose calculations are typically based on the population within 50 miles of the plant. Therefore, the resident population is included in that area. The amount of foodstuff produced in that area is also included. Some units may limit the population dose to the resident population, however, some highly productive farm areas may feed well in excess of the resident population. These “fed populations” may be included even though the actual individuals who will consume these foodstuffs are actually outside of the 50 mile radius. RG 1.109 includes recommended ingestion and inhalation rates for the three age groups used for population doses (infants are not required to be included). These intake rates are intended to be a reasonable typical value of the likely usage of a single individual. For example, an average teenager is defined to drink 200 litres of milk per year.

The biosphere models place the receptors in the environment using a polar array centred on the plant. Location is defined by compass direction and distance from a datum point at the plant. Since there are usually more than one release point at a unit, and may be more than one unit at a site, the actual distance and azimuth from the release point to the receptor can vary slightly between the actual release point and the biosphere model location. Plants use a sixteen compass sector grid, with distances defined in each grid. The biosphere model may include multiple locations downwind to account for the potential for lofting over the closest receptors, or may include only one receptor for each pathway in each sector. Due to the attempt to model the actual receptors, there may not be every kind of receptor in each direction (e.g. there may not be a dairy farm in each sector).

Dose calculations to the maximally exposed individual typically evaluate the dose for the maximum ground plane and inhalation dose residence, and then assume that those people also eat food produced at each of the maximum foodstuff locations. This is a highly unlikely and conservative assumption. The likelihood of a modern person doing that, including all of their meat and milk from a single source while also being the person at the highest inhalation location is very small. However, the argument can certainly be made that the inclusion of this highly unlikely level of pathway immersion provides additional conservatism to ensure that the doses are overestimated, given the simplifying assumptions elsewhere in the models.

For population doses, the distribution of population is laid out in groups by compass sector and distance. The dose to each of the polar segments is calculated based on the average intake usage parameters and the total population or food production in that sector and distance element. Population distributions may be estimated or derived from census data. Some locations have highly variable populations due to seasonal or even daily variations in populations which are unaccounted for. The fed population can be estimated from farm density or from county agricultural production data. However, both of these data sets have large areas for their minimum resolution, thus not providing details to the precision that can be derived from the diffusion models. Since the fed population do not represent resident people, given that the fed population may be larger or smaller than the resident population, the total population dose is distributed completely differently than the resident population is. Effluent doses are calculated as dose commitments. Therefore, residual environmental radioactivity is not tracked and carried forward into the next dose calculation cycle.

Although the current license limits are on the order of a few mrem to the hypothetical maximally exposed individual, typical actual doses are several orders of magnitude less on an individual basis. In addition, the extensive environmental sampling conducted through the radiological environmental monitoring programmes at the sites generally do not detect any residual radioactivity in the environment. A notable exception to this is activity in aquatic sediments, and tritium in surface water. Several cases exist where environmental monitoring, either specifically enhanced for the event or fortunately located have demonstrated that the atmospheric dispersion modelling in use is reasonably accurate for both very short-term (minutes) and long-term (months) releases.

For liquid releases, the process is very similar. A release point is defined, dispersion is applied, transfer factors are used to follow the radioactivity through the environment, dose conversion factors apply to the intake quantity and a biosphere simulation is used to define receptor locations and population distribution.

RG 1.113 provides considerable detail on modelling liquid mixing in the environment. However, RG 1.109 provides simplistic models that are defined as “acceptable” to the regulator. Depending on the ultimate dilution sink, the model requires simple choices on initial and final dilution factors, as well as shoreline deposit factors. Overall, the liquid model in RG 1.109 is far more simplistic than the atmospheric model.

Transfer factors are provided in RG 1.109. Some differentiation is provided for fresh and saltwater conditions, but as with atmospheric deposition, the values generally in use are the defaults provided in RG 1.109. Since considerable variation must exist by sediment character, fish or shellfish species, etc. the transfer factors are selected to be reasonably conservative for most conditions.

The liquid biosphere model is also generally simpler than that in the atmospheric model, primarily because the liquid dilution streams are mostly linear. Some recirculation can and may be accounted for in models for plants on lakes or bays where a well defined stream flow is not present. Receptors can be easily located for surface water usage, and simple and reasonable assumptions can be made as to the location of a maximally exposed individual for other exposure pathways such as fish/shellfish consumption and direct radiation from deposition.

Population distributions for liquid effluent doses are difficult to determine. Use of surface waters for drinking purposes should result in fairly well defined populations. However, treatment of surface waters may significantly reduce at least some radionuclide concentrations. Fed populations from recreational fisheries close to the site may be difficult to define. Local or state government agricultural departments may provide some fishery use data, but specifics for the limited regions of interest for near field and far field exposures will be unlikely. Fed populations for larger dilution sinks such as major bay or ocean sites will also suffer from inaccuracies in assumptions on the extent and location of commercial fisheries. Common practice is to overestimate the impact of these fed populations in order to ensure that the environmental doses are not underestimated.

Although calculation of population doses is not required, some plants do so as a part of public outreach information. Using the intentionally conservative processes described above, total population doses on the order of hundreds of person-mrem to a few person-rem have been reported. Given the populations involved, these are equivalent to average public doses on the order of thousandths of mrem or less per person.

Optimisation

Plant technical specifications require that radwaste processing systems be available and be used unless waste streams are below specific concentration limits. In common practice, however, plants routinely make every effort to operate these systems beyond the minimum requirements. This is evident in the dose results. Maximum individual doses are seldom close to the 10CFR50 design guidelines, which themselves are lower then regulatory public dose limits. Plants simply operate the systems all the time. There is little likelihood of a plant deliberately releasing without processing unless the plant is in an upset condition.

Plants continue to improve water chemistry and system availability. These are positive economic drivers to reduce effluents. Improved chemistry reduces liquid waste while increasing the reliability and long-term worth of the facility. Effluent control is a significant public relations issue. Plants specifically exceed requirements in order to improve the environmental perception within the resident communities. Several plants have implemented zero liquid discharge policies. Such self-imposed limitations greatly exceed regulatory requirement. Such efforts may significantly increase costs and in fact may have a net increase in population person rem due to the increases in doses to plant staff to perform the extra effort to reuse water. Water that is acceptable for release, both from a radioactivity, and more importantly from a chemistry quality standpoint, may not be adequate to be returned to the plant without additional and expensive processing. Given that population doses are typically at most a few person-rem, costs for minimising effluents are frequently astronomical on a cost per avoided dose basis, and may, as noted above, not actually avoid and total dose due to the increased dose to the plant staff.

Operational requirements seldom provide for significant variation in radwaste/effluent handling. Although the plants will thoroughly process liquids, and perform the required long-term hold-up on waste gas for decay for example, plants will not retain these effluents longer in order to wait for more optimum environmental conditions. This is primarily due to a lack of reserve space.

A PWR will isolate and allow a waste gas tank to decay as long as the second tank is not yet at capacity. However, as there are usually only two WGD tanks, the plant cannot hold a full tank for weeks or months longer waiting for optimal dispersion or wind direction. Similarly, liquid effluents are processed to a sample/test tank. There are usually two of these tanks, so that one can be being filled while the other is being sampled and then released. At a plant on a river, for example, the test tanks are not held for months waiting for the spring freshet. This is impractical and not possible given the limited capacity. Adding tankage would be vastly expensive for little gain in population dose reduction.

BWRs primary atmospheric releases are from the continuous condenser offgas. However, BWRs have a filtration and hold-up system to process this off-gas flow. These systems are in continuous use unless in upset condition. Plants routinely achieve availability percentages in the high 90s for these systems. At BWRs, when there is little fuel leakage, the off-gas releases can be many orders of magnitude less than the off-gas system was designed to process. In fact, releases with the system off with good fuel condition can be less than releases with the system in service with less then perfect (but still acceptable) fuel condition. Even in such cases, the systems are still used, despite the added expense and effort required. Plants really do not assess effluent releases and effluent processing decisions based on population dose optimisation. Wastes are processed as designed, effluents are released in a controlled manner to minimise concentrations, and wastes are generally processed far more than strict cost/benefit optimisation would be likely to indicate to be needed.

Generally, routine practice at US power reactors is to reduce effluents well below their license requirements. There are many reasons for this, including environmental stewardship, public relations, lack of clear optimisation requirements, and regulatory perception. The net effect of this is that effluents are minimised with a best effort process rather than an optimisation process. A formal optimisation in all likelihood would indicate the need for less effluent reduction than is currently routinely practiced. In such cases, however, it is unlikely that any changes in behaviour would occur. Plants that are zero liquid discharge, for example, are well aware that it costs more than putting the waste in the environment. Quantification of that fact would be unlikely to outweigh the already perceived benefits in terms of regulatory and public perception.

Since portions of the doses delivered from a plant may actually be to individuals hundreds of miles away due to transportation of foodstuffs, and given the highly mobile and fluid populations common at many plants (since many are actually in seasonal tourist areas for example), any effort at increasing the precision and granularity of population dose estimates would be difficult and expensive.

Appendix 3

Examples of the Use of Collective Dose in Optimisation

Use of collective dose in optimisation in Romania

Basis of utilities optimisation system

Based on ICRP recommendation and having in mind the precautionary principle, the nuclear industry has assumed, starting in the 1990s, a challenge to demonstrate the application of the optimisation of occupational doses.

Over the years this challenge has also taken legal aspects by being incorporated in the legislation of the majority of the countries having a nuclear programme. In this respect, the inclusion in legislation has been implemented from just mentioning the principle of optimisation up to detailed guides issued by relevant regulatory authorities, showing how the application of the principle might be attained.

Becoming a legal requirement, the industry developed its response by defining programmes and using tools to show the compliance to the legal requirements. One of the major tools is the use of collective dose in assessing the optimisation performance and an indicator frequently referred in optimisation programmes.

Application

Overall an optimisation programme is developed in a number of components. Hereafter are presented the main areas, with the focus on the use of collective dose.

Work management process

In the process of work preparation and assessment, specific steps have been defined to assess the collective doses. At this stage the detail of optimisation review ranges from just checking the existence of standard procedural provisions for radiation protection, up to detailed analysis of the activities with the aim to provide further protection measures.

Normally, the first level of review is formalised in checklists, which lead the reviewer through verifying the respective activities against standard work practices and protection measures, which will warrant control of exposures. All these checklists include, in a condensed form, all the lessons learnt from past practice.

Example of checklist

US reactor checklist – radioactive work order review[3]

Pre-job review questions:

1. Has the job history been reviewed?
   (a) If no, have plans been made to start or improve files during this job?
   (b) Will the use of photographs or videotapes be helpful? If yes, indicate by name who will take photographs and/or videotapes.
2. Have job interferences been identified (i.e. anything that may hold up work progress unnecessarily)?
3. Is the job a high risk or first time evolution?
4. Will special training or mock-up training be required? If yes, indicate schedule, location and type.
5. Will remote handling devices or monitoring be utilised? If yes, specify.
6. Does all the work need to be performed in a radiation area or airborne area? Specifically, can the component(s) be moved to a lower dose area? Has prefabrication outside the radiation area been considered for the new components being installed?
7. Can area dose rates be reduced through the use of shielding or system flushing (to remove the source)?
8. Have alternate work methods been identified for exposure reduction potential? If yes, what alternate methods were identified?
9. Will the job necessitate a radioactive system breach?
10. Has a tool list been developed and verified to be accurate?
11. Will special tools be needed? If yes, what type and are they staged?
12. Will the job generate radioactive waste? If yes, what type (e.g. liquid, dry active waste, metal) and approximate volume?
13. Have job site communication requirements been determined? If yes, describe.
14. Has the work area been reviewed for environmental conditions and restrictions? Describe any limiting conditions or restrictions.
15. Has the word order and procedure been reviewed to identify radiation protection hold points (i.e. work steps that could result in the radiological conditions changing)?
16. Has a list of available, qualified members of the work crew been reviewed to ensure distribution of the crew's doses?

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3. IAEA (2002), *Optimisation of Radiation Protection in the Control of Occupational Exposure*. IAEA Safety Reports. Series No. 21, Vienna.

On the other hand, the process of detailed analysis makes use of more sophisticated techniques with the aim to:

- provide more detailed assessment of work activities, for a better quantification of doses;
- identify critical activities in term of dose;
- refine the dose assessments;
- identify additional measures, whether organisational or additional/ more performance hardware to lower the doses;
- benchmarking comparison to the previous dose results for similar jobs, executed within the plant or external experience.

Usually, the trigger for detailed analysis is based on collective dose indicator: above a certain level (around tens of man-mSv), work is required to go through a more detailed analysis. Moreover, based on the level of collective dose, the results of assessments are approved at different organisational levels, higher collective doses requiring higher level of approval.

Example of collective dose trigger

The categories of job and related ALARA reviews proposed by the National Council on Radiation Protection and measurements for uclear power plants[3]

Category	*Dose estimate*	*Review*
1	<10 man-mSv	By a radiation protection technician as part of a radiation work permit preparation.
2	10-50 man-mSv	By a radiation protection technician and radiation protection supervisor.
3	50-500 man-mSv	By a radiation protection supervisor and engineer responsible for ALARA planning. Dose estimate and planned dose reduction techniques to be documented in a pre-job report to management.
4	>500 man-mSv	In addition to the above, review by the plant's management or an ALARA committee.

One aspect, which is worthwhile to mention, is related to type of doses taken into account in terms of type of exposure. Thus, job doses are established usually for external exposure component, due to inherent limitations of assessing and assigning internal doses to a certain job.

Dose targets

One of the important elements of the system is the dose target. Usually this is established based on collective dose indicator, and it has different levels (annual, outage, and group level).

Whilst the dose targets at more generic level are established whether for total collective dose or breakdown in external and internal exposure, at job level these are established usually for external exposure component, due to inherent limitations mentioned before.

In certain utilities, dose targets are part of the incentives system.

Example

ALARA Committee[4]

To meet this objective, the NPP set up an ALARA Committee. This committee is lead by a member of the site management (the deputy manager of the NPP) and by the radiological protection staff.

The Committee is composed of:

- all departmental heads (maintenance and production);
- a company medical occupational doctor;
- a member of the site Communication staff.

The ALARA Committee has the following objectives:

- fix set up the annual objectives of the site;
- select the important actions;
- undertake the main actions;
- allocate necessary means (budget);
- appoint site representatives in national groups.

For each important area, one local working group is designated. These groups report to the ALARA Committee.

Their objective is to propose a methodology and an operative mode to bring the dose to a low level; the lowest in the "All the French Nuclear Units". They are composed of a leader, motivated operational employees, representatives of the radiological protection staff as well as contractors involved in the works site.

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4. NEA (2003), *Occupational Exposure Management Nuclear Power Plants*, Third ISOE European Workshop, Portoroz, Slovenia, 17-19 December 2002, OECD, Andersson, M., A. Holmqvist, J. Möller, "A Swedish Dose Passport – Contractors point of view", (Portoroz symposium paper), Paris.

Example

Collective dose goals at Kozloduy NPP in Bulgaria

Annual collective dose is used as an incentive target at the Koszloduy NPP in Bulgaria. The target is displayed on monitors around the plant, and the year-to-date collective dose, as a percentage of the target value, is also displayed and updated every three to four days. Workers are encouraged not exceed the target collective dose, and to suggest approaches to reduce dose to the ALARA committee to help the plant to meet its goal.

Review and follow up

Another topic in the optimisation system is related to provisions for analysis and feedback of job performance, with respect to radiation protection. This analysis is performed at different levels; covering the post job analysis, station trend analysis for different breakdowns or external benchmarking.

In the case of post job analysis, at the end of work performance a work leader is required to review the activity, and provide feedback to a specialised group, i.e. radiation control section, with the main scope to capture valuable work experience and provide input data for job dose trending (collective dose, man-hours work, actual fields).

The station trend analysis focuses on comparative evaluation of collective doses between workgroups, dose trends for different workgroups or for station collective dose, with the scope to identify adverse trends and corrective actions consequently.

The external benchmarking is on comparing against dose data from similar plants, in order to have an external measure for station performance.

Example of post job feedback

CEPN checklist – Feedback experience meeting, Guide sheet[3]

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.

1. Were the tools and equipment required for the operation available at the right time?

2. Was the zone prepared and ready for your task on your arrival?

3. Were the protection measures suitable for the task executed in this zone?

4. How much time did you have to prepare the task? Was this long enough?

5. Did other tasks interfere with yours?

6. Was the work location kept clean and orderly so as to ease your work?

7. Was the full team aware of its exposure? Did you insist on this exposure being limited as much as possible?

8. Was the entire team aware of the site dose targets? Was the team motivated?

9. Were there any problems of co-ordination with other specialties, other departments or other workers?

10. What problems did you encounter that could have resulted in higher doses?

ALARA committee responsibilities[3]

In some facilities it may be useful to create specific ALARA management structures to facilitate the co-ordination and implementation of actions. These structures may include:

An ALARA committee. This committee is responsible for approving and reviewing the ALARA plan. It meets periodically to review the performance of the facility concerned in relation to radiation protection, to evaluate suggestions for reducing doses and to make recommendations to higher management.

Members are generally selected to provide a wide range of technical backgrounds to the committee and to ensure that the various work groups are represented.

An ALARA co-ordinator (or ALARA group). This co-ordinator (or group) verifies that the decisions taken by the ALARA committee are implemented. He or she is also the designated contact person between the workforce and management for discussing radiation protection issues. When a group is created it is usually composed of engineers, health physicists and technicians, and is in charge of performing a detailed analysis of jobs suitable for ALARA.

Supporting tools

In order to support the use of collective dose in the optimisation process, the industry developed and implemented a series of tools as detailed below.

Monetary value for dose

The concept of monetary value of dose is also denominated as “alpha value”. The specific use of this tool is to support detailed analysis of complex jobs and the decision-making process for major modifications.

There are a number of methods to derive, but basically they relate in one way or another to the wealth of the respective country where the utility is located or the willingness to pay.

One other characteristic is the derivation by a number of companies of a system of monetary values, related to the level of individual doses: the higher individual doses the higher the monetary value. However, even though this approach is taking into account individual doses, in practice it is more difficult to apply due to the need of additional judgment which category to include.

Another aspect is related to the frequency of use: even though this is a powerful tool, taking into consideration the fact that it implies a more detailed analysis, it is not frequently used.

Examples

Monetary values/frequency of use[5]
During 1997, a survey was performed within the ISOE network to better understand the usefulness of the monetary value of collective dose in the practical application of protection optimisation. This value is commonly referred to as the "alpha value".
Eight regulatory authorities in charge of radiological protection (Canada, Czech Republic, Finland, Netherlands, Sweden, Switzerland, the United Kingdom, and the United States) responded that they explicitly refer to the concept of monetary value of collective dose as a baseline reference for their regulatory decisions, and have defined one value or a set of values for this quantity. They also considered the implementation of the ALARA principle within the nuclear industry to be mainly an industry concern, and that, in this context, the monetary value of collective dose is essentially a managerial tool.
In most countries, alpha values are used when making decisions related to budget and impact on the operation and safety of a plant. About 60% of these uses are associated with significant modifications, large and expensive repairs, or chemistry of the plant.
As of 1997, nearly three quarters of the utilities represented in ISOE had set up their own alpha-value system. Some use a single alpha value, the average of which is about US$ 1 300 per man-mSv for North American utilities in the year 2 000 and US$ 600 per man-mSv for utilities in non-OECD countries. European utilities have established sets of monetary values which increase commensurate with increased risk. Mean values within this group, of about US$ 1 000 per man-mSv, do not differ drastically from those observed in the other groups.

Data bases

The other tools support the trending and the need to benchmark. Specifically this refers to the databases developed to capture dose/dose related information. These databases are developed at utility level, to support dose target setting or are at international organisational level, which usually support benchmarking.

5. NEA (2002), *ISOE Information System of Occupational Exposure: 10 years of Experience.* OECD, Paris.

ISOE database[5]

The field of occupational exposures at nuclear power plants has benefited since 1992 from an international programme called the Information System on Occupational Exposure (ISOE). This programme was launched by the OECD/NEA to facilitate the exchange of experience in the management of occupational exposure among utilities and regulatory authorities from around the world. Since 1993 it has been co-sponsored by the IAEA to allow the participation of member countries not in the OECD/NEA, and in 1997 the two agencies formed a joint ISOE secretariat.

The ISOE programme includes the management of an international database on occupational exposures and a network that allows the participants to obtain or exchange all types of information that relates to radiation protection in nuclear power plants. At the end of 2000 data from 92% of the world's operating commercial nuclear reactors were included in the ISOE database.

The ISOE provides each member utility with the database, which contains detailed information on the individual and collective doses associated with the major activities performed in and outside refueling outages, a description of the specific design features of the various reactor types and forms for the feedback of experience from some specific jobs performed by some utilities. An annual report contains an analysis of the data and a summary of the principal events in the participating countries that might have influenced the trends in occupational exposure.

Results

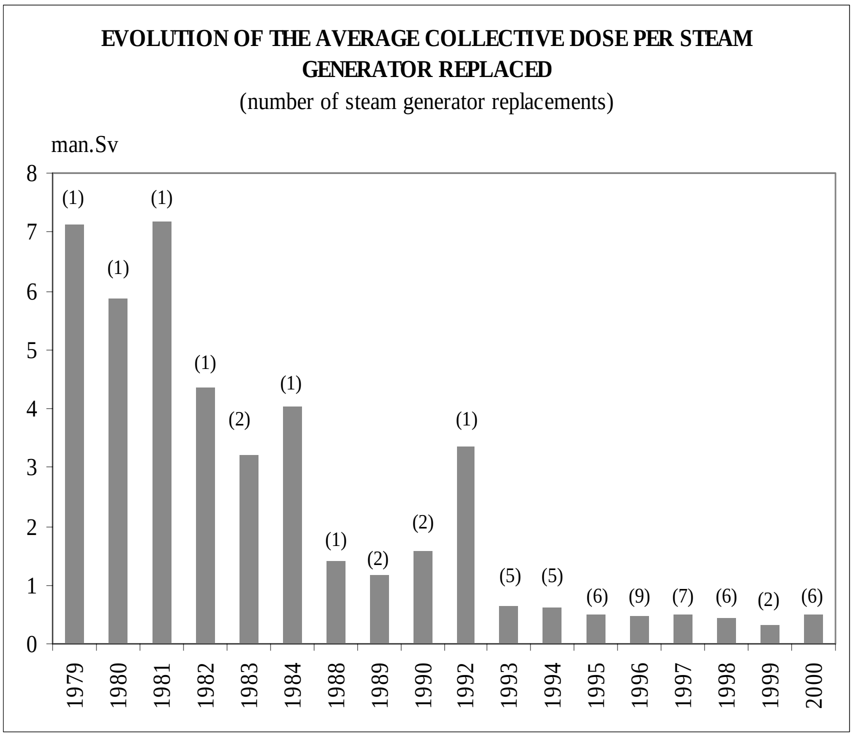
Over the last years, collective doses showed a clear decreasing trend. Thus, according to ISOE database the following trends have been observed. These trends are closely related to the aggressive development of optimisation programmes.

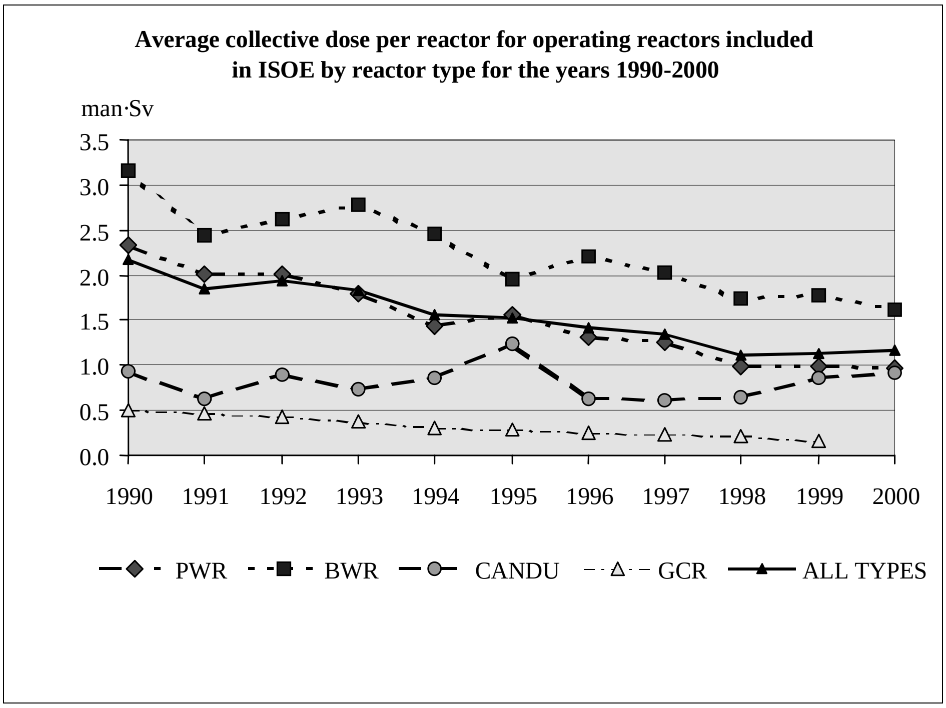
Example

Evolution of the average collective dose per steam generator replaced steam generator replacements[5]

Between 1979 and 2000, 59 steam generator replacements (SGR) were performed, mainly in North America and in Europe. Collective doses decreased regularly from more than 6 man-Sv per steam generator replaced in the late 1970s-early 1980s to an average of about 0.5 man-Sv during the last six years (see Figure).

However, that average masks quite large discrepancies and the best results correspond to three SGR performed in 1996 and 1998 in Belgium and France with only 0.21 man-Sv per steam generator replaced.





Challenges in application

Nevertheless, during the application a series of limitations have been observed and care should be taken to this topics.

Precaution in application of man-Sv value

Inherently, all the existent models have built in subjective elements. This should not lead in providing a lower level of protection, if using the human capita approach or inadequate allocation of resources, in willingness to pay approach is used.

Precaution in the use of collective dose as an indicator for optimisation

The collective dose is an aggregate indicator it should be used with precaution and in conjunction with a judgment of the distribution of individual doses. A useful tool, but with limited application as shown before, is the use of multiple monetary values for different levels of individual doses.

Precaution in sole use of collective dose in benchmarking

When comparing against other plants, the collective dose performance should not be taken by itself. There is a significant number of factors like the age of the plant, operational history, design of the plant, which should be considered along with the collective dose. Also appreciation should be given to the trend of the collective dose and the slope.

Precaution in application of dose targets for jobs

This is related to the fact that there are technological limitations in assessing internal doses, and thus the targets system should consider fully these limitations.

Appropriate balance between use of standard protective measures and detailed analysis of protective alternatives

In the day-to-day work activities, there are a number of techniques and standard practices developed over the years and documented in work procedures. On the other hand, all utilities rely on specialised people with high experience in the application of RP protection measures.

Altogether when applied in consistent programme, these provisions may warrant appropriate protection of workers without further need for formal optimisation process for the majority of jobs.

Appendix 4

Examples of Worker Empowerment

Worker empowerment in Romania

Background

In the context of optimisation of worker exposure, another key aspect is the participation of worker. It is the worker, in the end, who is responsible for maintaining his or her own dose ALARA, and thus the participation of the worker in discussing dose objectives, and the means to achieve these objectives can be very important. This has been termed, by many, including the ICRP, as empowerment of the workforce.

In more practical terms, several topics need to be dealt with, as detailed below:

- the level of knowledge the worker should have about the risks at which he/she might be exposed as a radiation worker;
- the level of information about the risks involved in a certain work (participation in the preparation of protection plans, review of the protective measures);
- level of decision the worker should have with respect to protective measures to be taken;
- the influence of worker in the policy decisions.

Implementation

In the practice of radiation protection (RP) there are several practices, which can further develop the way of implementation.

Specific radiation protection training

All the utilities are providing RP training. The scope and extent of training varies on a large scale, from an extensive training for a large number of people, required in the plants which use the self protection philosophy, up to more limited time (few days training) for the majority of employees, in the case of the rest of the plants.

Basically this type of training provides the workers appropriate information on radiation risks they are to be exposed to and at least a basic understanding of the respective facility specific risks (types, location and magnitude), as well as knowledge on specific RP procedural controls. Again, depending on the time allotted, training topics may cover development of practical skills.

Direct involvement of worker in the preparation of protection plans for the work

In the case of self protection philosophy, a large number of employees are entitled to prepare protection plans, provided they hold appropriate RP qualification, issued based on training and experience.

Review of protection plans

All the utilities have included in their programmes provisions for informing the workers on the risks they are going to be exposed for a specific job and the protective measures to be taken during the work execution. Normally, this is part of the work control process as the pre-job briefing.

Example of pre-job briefing form

US reactor checklist – ALARA pre-job briefing[3]

1. Describe a brief sequence of events.
2. Describe the work area from the list of concerns below:

   (a) radiological conditions at the start of the job;

   (b) potential radiological conditions and/or hazards as work progresses;

   (c) access routes to and from the work area;

   (d) identify low dose waiting areas for the staging of equipment and/or support personnel;

   (e) environmental conditions and restrictions;

   (f) shielding concerns;

   (e) environmental conditions and restrictions;

   (g) safety hazards (e.g. heat stress, confined space entry).
3. Describe the equipment and/or methods to be used to control the generation or spread of contamination and to minimise the potential for airborne radioactive material.
4. Describe the housekeeping and system cleanness that precludes foreign materials from entering open systems.
5. Describe the requirements, placement and use for dosimetry.
6. Describe requirements for protective clothing, equipment and respiratory protection.
7. Describe the dress and/or undress methods particular to this job.
8. Describe the techniques of volume reduction for radioactive waste and considerations for special waste (e.g. oils, packing, filter, mixed waste) handling and generation.
9. Have all the action items identified on the ALARA job planning checklist been completed? If no, what items remain and who has responsibility for their resolution?
10. Open the discussion to solicit comments and concerns of the work crew.

Worker feedback

All the utilities have included in their programmes forms to capture the worker's feedback on RP issues. Mechanisms used cover:

- specific job improvements;
- general interest topics, for which specific feedback forms have been initiated.

Challenges

Development of a radiation protection training programme

When implementing an RP training programme, the cost aspects should be considered with precaution. Thus, whilst extensive training implied by self-protection is providing flexibility and very knowledgeable workforce, the cost involved is significant.

Relation to administrative system of decision making

In developing a system to provide for participation of workers in decisions related to their safety, should clearly define the boundaries with the administrative decision making for work processes, in order to avoid misinterpretations.

Worker empowerment in Spain

Since the beginning, ISOE has encouraged the worker involvement within the radiation protection programme and more specifically within the optimisation of radiation protection or ALARA programme, but the decision-making process concerning the definition and implementation of the radiation protection programme and the allocation of resources should still remain at the top management level.

In other words, only within the optimisation principle the stakeholder participation can be accommodated and not within the justification principle nor within the limitation principle. For instance, there is a high risk that unions will propose values so low that they are almost impracticable or that will end up with the closure of the facility or with the investment of enormous amounts of money, if they are invited to define practical operational dose restriction levels.

Which are the important factors that best contribute to implement and maintain worker involvement under the radiation protection or ALARA policy?

Some of these factors are addressed below and those should define the whole context where ICRP should develop its guidance regarding stakeholder's participation at the worker level. ICRP recommendation to "*involve bodies directly concerned (including representatives of those exposed) in determining or negotiating the best level of protection in the circumstances*" at this "occupancy" level must not go forward. Main responsibility in determining the best level of worker protection is a non-delegated attribute of the management level and must remain non-delegated according with most common international and national regulations, common sense and protection of the investment.

The following information has been extracted from previous ISOE publications and reflects their recommendations concerning worker involvement within the framework of the principle of optimisation of the radiation protection or ALARA, which is the only principle where worker involvement applies.

The ISOE point of view is that worker means a whole hierarchy of personnel, ranging from management level to the worker itself.

Worker involvement

A fundamental issue which influences many of the stages of a job is the performance of the worker. By engaging the worker in the task being performed, the worker is more likely to be motivated to perform the job to the best of his/her abilities. This will be reflected in lower job doses as well as in higher job quality.

Features defining worker performance under the ALARA concept

A good worker is expected to contribute to the ALARA concept by performing his job with high quality, low dose, and if possible with low cost. For this, the worker must be well educated and trained in the technical aspects of the job.

Considering good performance of workers with respect to ALARA concepts, features other than technical knowledge and experience are important such as:

- Personnel must know the philosophy of ALARA to understand management intentions, to be able to reflect these general ideas and to put them into practice in the local work area during jobs for their own safety and the benefit of the utility.

- As a “tool” of ALARA work, everyone must know and apply good radiation protection practices nearly automatically in the work place.

- Workers are expected to think about the work to be performed and to try to improve performance within procedural requirements, using their own experience.

- Workers should be aware of potential problems and should be able react to the occurrence of unexpected problems in a sale and efficient manner according to their knowledge and assignments.

Those are some of the more important practical factors, which may be considered to contribute to the good performance of a worker, and to the improvement of ALARA concepts in a plant. There is, however, a very important and very basic background which will steer this behaviour psychologically: only personnel motivated to perform according to these features will perform as necessary, whereas de-motivation will hinder application and worsen performance. As such, the motivation of personnel will be the most important factor in worker involvement, and will govern the application of the ALARA principle to all aspects of the work.

Conditions to the implementation of worker involvement

General behaviour of management

Work management to optimise work, in terms of dose and cost, is an approach which must be supported and applied by all levels of staff at the plant. To involve workers in this approach, it is important for them to see that management at all levels is convinced of work management as the most important – if not the only – tool for keeping doses ALARA. It is also important that all members of the management chain apply this tool to improve the performance of the plant.

Education and training to implement and follow the ALARA approach

Personnel must be educated, and to a certain extent, trained in the ALARA approach and its tools.

Education in the case of worker involvement in the ALARA approach is meant to deal with basic concepts of ALARA and good practices in radiation protection, and to give the personnel the important knowledge for responsible work in the frame of ALARA.

Worker involvement in planning of actions

Due to the experience of personnel specialised in outage work it is important to integrate personnel in the planning, scheduling, and preparation phases of jobs. This aspect may cover the consideration of tools and techniques to be applied during jobs, the harmonisation of actions to be performed, and improvement of procedures during work preparation.

Involving personnel in reviews

For the planning of actions, work management can benefit from the experience of personnel through post-job reviews. This is supportive in two ways: on the one hand, workers involved in post-job reviews will be motivated to improve as their knowledge and their experience is accepted and requested On the other hand, use is made of a job performance experience, which can be evaluated for improvement.

Here the precept is that the person closest to the job task best understands the work and is best able to suggest time and dose saving changes to improve the job or process being performed. It is appropriate that the average worker believes that valuable ALARA ideas have an avenue for management consideration, development and implementation into the plant's work methods.

Assignment of personnel

Assignment of personnel may address work planning and implementation factors as well as personnel involvement. Considering the latter, assignment of personnel should assure that workers know their tasks and are able to perform their duties with competence, efficiently with low dose and high quality, and in a short time. This could also increase the motivation of the workers involved.

Involvement of personnel by setting goals

The use of goals for the workers can be motivational and challenging, and so will increase involvement. Goals such as job collective dose, daily dose, individual dose, total man-hours, etc. can encourage workers.

It may be interesting and may contribute to the motivation of the personnel to benchmark where their plant performance falls relative to industry performance (WANO and ISOE).

Information and communication to improve involvement and motivation

Workers should be regularly informed of the intentions of management and open questions should be answered as soon as possible.

On-the-job training and implementation phase, with the support and participation of senior management in motivating workers through the use of information and communication/discussions is also essential.

Communication at the worker and senior staff level, on a team basis, will support intentions to implement ALARA procedures by information transfer and exchange of experiences.

Incentives to motivate and involve workers

ALARA incentives or recognition programmes are another technique used to motivate groups of employees or contractors toward achieving dose reductions by linking goals set for jobs to competitions.

ALARA awards and incentives are not only used to recognise good dose performance on jobs but have also been used, with equal or greater benefit, in encouraging ALARA suggestions from workers.

Summary

The involvement of workers at all levels is one of the most important aspects of a good radiation protection programme. By engaging the worker in the task being performed, the worker is more likely to be motivated to perform the job to the best of his/her abilities, and this will be reflected in lower job doses as well as in higher job quality. To assure the full involvement of workers, conditions must be correct to create and then to maintain such involvement. A programme to reach these goals should stress the correct behaviour of senior and mid-level management, as well as of senior staff members, and should involve an appropriate level of training such that workers posses the correct tools for the implementation of ALARA. It should also implicate workers at all the stages of a job and should assure that there is a mechanism for matching individuals and their skill levels with appropriate tasks. Workers should also be included in the process of setting goals, and good communications between different levels of the hierarchy and among the different disciplines should be a management priority. Finally, worker incentive and "challenge" programmes should be used to create and maintain worker involvement, and periodic refresher training in work practices and ALARA should be used to reinforce good habits. Such a programme will help to assure an appropriate level of worker motivation and involvement, and should pay for themselves in terms of time, dose, and costs saved, and in terms of job quality.

Appendix 5

Examples of the Management of Itinerant Worker Exposures

Approaches in Romania

Context

Lately the nuclear industry is facing new challenges with respect to the protection of attached staff. Even though attached staff topics have been addressed for many years, lately there are some developments which have changed the magnitude of this topic.

Historically, specialised services represented the main source of external workers. These people are normally involved in inspection activities of reactor active systems, thus being involved in high dose jobs, for which there are always reserves to optimise the exposures.

In the last years, the competition on the electricity market and economy globalisation either led to increase in the magnitude of external specialised services or added a new category of common services, which do not involve a high level of technical expertise, but still may involve work in high dose fields areas.

Thus, the downsizing of operating organisations further leads to externalisation of certain common services and thus providing services to several utilities. Under these circumstances a significant number of employees leave the jurisdiction of operating organisation.

Another factor is related to the higher mobility of the workforce, due to the opening of work markets, by international agreements. Again this is making a higher rate of personnel change in the attached staff category.

Particularities

Nevertheless, much of the protection and optimisation practices as provided for permanent employees are to be applied to attached staff. However, there are some particularities of this workforce which need to be addressed in a different manner or there is the necessity to design and implement new provisions in the protection system. Main particularities are summarised below.

Lower level of knowledge on specific protection measures

Due to the fact they spent short time in a certain facility, attached staff do not have the opportunity to practice and learn more on the respective facility protection measures, the type and magnitude of specific radiation hazards, in comparison to permanent employees.

Different rules

Itinerant workers are usually employed by large companies, based in a different country than the utility. Consequently, all these companies have developed their own system of protection, compliant to their home regulations. Inherently, when providing services, the likelihood of inconsistencies is high, which might adversely affect the standard of protection.

Shared responsibilities

Permanent utility employees have a detailed individual contract, where there are clear responsibilities assigned to each party for the work in the utility premises.

On the other hand, during the performance of work they do not have automatically direct contractual agreements with the utility representatives at the work place; some of the decisions which are normally made on the spot require longer consultation, putting in this way pressure on work activities due to delays required by this consultation.

Language barrier

The last but not the least important particularity is due to the globalisation of the economy. Lately, a number of multinational service companies were created, which on the one hand made them more competitive, but the number of foreign employees increased.

Communication has been affected, during work performance or imposing additional barriers for understanding the training courses.

Application

In response to the specifics of attached staff, utilities have included in their RP programmes specific provisions or interpretation of their rules. Main provisions are summarised below.

RP aspects included in contractual arrangements

Usually, there are specific provisions added to commercial contracts, which address the RP aspects like type of training which is to be provided, requirements of proofs for dose history and medical fitness, communication and reporting of RP data, establishment of dose constraints applicable during the attachment period.

Example

German legal demands for us as a contractor using Swedish dose passports[4]

The legal demands on a contractor company as a contractor on German nuclear installations are based on the German Radiation Protection Ordinance.

In our case we sent the application to LfU in München. The processed the application and agreed on a license for a 5 years period. However, the license is coupled to several demands before the license can enter into force in Germany.

1. All of the German nuclear installations that we visit must sign an agreement with us on the health physics issues. The holder of the license must prove to LfU that an agreement, regarding administrational and organisational issues related to health physics, has been made between Westinghouse Atom and the relevant German nuclear installations.
2. The holder of the license has to present a radiation protection instruction regarding the internal routines relevant for health physics.
3. All of our external personnel have to be listed. The holder of the license is responsible for ensuring that the listed workers receive proper information about the conditions on the relevant nuclear installation.

4. The holder of the license must, without delay, inform the person responsible for radiation protection of the nuclear installation if the activity or dose limits are exceeded.
5. The holder of the license shall:
   - measure the dose with a TLD qualified by the Swedish competent authority, SSI;
   - make sure that the listed workers carry the dosimeters provided by the installation;
   - let the workers go through whole-body measurement at LfU's qualified measurement station for radio toxicology.
6. The holder of the license has to make sure that the external personnel follow the instruction given by the health physics office on site.
7. The holder of the licence must update the Swedish dose registry as well as the dose passports.
8. The results from the monthly dose evaluation of the listed workers have to be forwarded to LfU every month.
9. The list of workers has to be sent to LfU once every third month or when there are changes done to the list.
10. The Swedish dose passports have to be registered at the LfU.
11. When a listed worker stops working at German nuclear installations, the dose passport shall be left with him.

The agreement between Westinghouse Atom and the nuclear installations has not yet been reached.

Therefore, we are still working with German dose passports for our external personnel.

Use of incentives based on RP performance

In order to increase the ownership, utilities include contractual provisions related to radiation protection performance.

Common training programmes

In order to optimise resource allocation, utilities established common agreements for mutual recognition of RP training and qualifications obtained within the pool. This approach is applied in the case of utilities within the same country.

Long-term contracts

One of the means implemented in order to address the stability of attached staff is the use of long-term contracts. This approach is positively influencing the service companies’ human resources policies and further assuring more experienced and knowledgeable attached staff.

Challenges

Whilst utilities have taken provisions to address issues related to attached workers, there are still a number of challenges, which require further efforts. Whilst some of them are whether inherent and not much can be done to change (i.e. moving of workforce or language barrier) or the improvements are up to the mutual agreement (i.e. harmonisation of training programmes and finding means to stabilise the attached staff), there is a challenge which once positively addressed by the RP community may significantly improve the situation. Specifically this is related to high diversity of RP requirements.

Especially in the case of transboundary workers, the diversity in national requirements imposes a lot of effort, prior starting the work, without a significant added value. The harmonisation of national legislations on specific requirements for attached staff would be very much welcomed. From utilities point of view, an international “RP passport” should be the target.

Appendix 6

Examples of Optimisation Tools

Example from Slovenia

Within the context of the optimisation of radioactive releases from nuclear facilities, ensuring an appropriate level of protection, and taking into account of existing societal concerns, the authorities may use some specific tools. These tools authorise limits for the source such as:

1. dose constraint for the plant site;

2. dose constraint for the overall nuclear fuel cycle;

3. yearly activity limits imposed to the specific effluent releases from the source.

ALARA and BAT

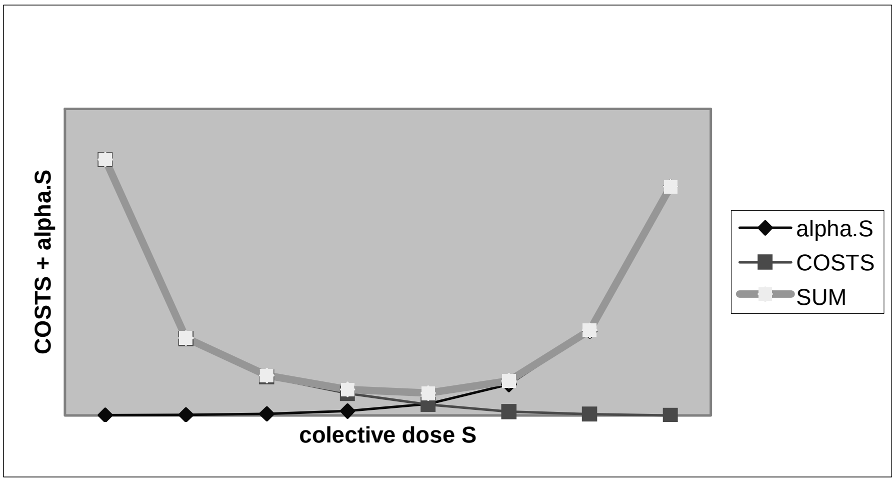
Regarding optimisation of the operation of the facilities and techniques in use, there may be slightly different approaches, such as the concept of "as low as reasonably achievable" (ALARA) and "best available techniques" (BAT). BAT is used in different areas of effluent release optimisation.

ALARA as optimisation principle

ALARA is one of the basic principles of the system of radiological protection and in this case is used to assure that the control of the discharges is optimised in accordance with the principal requirements of the safety standards for protection against ionizing radiation and for the safety of radiation sources. In this context the operators should keep all radioactive discharges during operation of the facility as far below the authorised discharge limits as is reasonable achievable.

The cost-benefit analysis in the case of using collective doses and alpha monetary value may not be an appropriate way to address the ALARA of effluent releases. It is possible to show this approach by Figure 1. It may be difficult to find an appropriate monetary value of man-Sv or to have an important collective dose of public to be optimised. Instead of collective dose some other parameters might be used.

Figure 1. Example of optimisation – graph of cost-benefit analysis



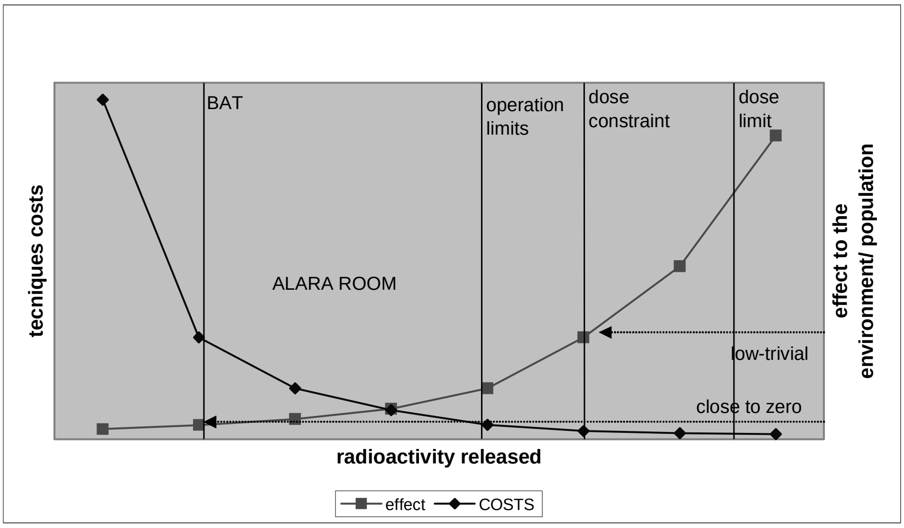
ALARA in the case of effluent control

Beside respecting the authorised limits, which are dose constraints and/or radioactivity release limits for operation, the operators should achieve ALARA effluents by optimising the procedures and the practices. The Figure 2 may show “ALARA room” available to the operator or licensee.

On the left side of “ALARA room” the line illustrates the best achievement of optimisation using the BAT and ALARA approaches at the same time. ALARA should be implemented in the complete chain from the fuel leakage prevention to the radioactive waste management and effluent control. Best available techniques or technology can be understood as ALARA in design.

On the right side of “ALARA room” are authorised levels, which should be always respected as limits for operation.

Figure 2. ALARA in effluent control



Example from Japan

Constraints or protective action levels in ICRP new recommendations

Public exposure

The case

The dose constraint (0.3 mSv/year) is recommended and the dose limits as individual dose restrictions are not included in the recommendations.

The necessity of dose limits

If this idea is applied for workers who work in nuclear power station grounds (general areas), their dose might be controlled under 1.5 mSv/year taking account of residence hours (2 000 hours per year). This might mean that the workers dose will be controlled about three times more severely than the present control value (in Japan).

(Rules in Japan: General workers in nuclear power stations are the public, so their doses are limited under 1 mSv per year. The dose of the radiation controlled areas boundary is controlled less than 1.3 mSv per 3 months.)

When another source can be ignored, the dose limit (1mSv per year) should be used. Thinking of the actual situations and results, flexible ideas are important in the radiation protection.

The occupational exposure of women

Publication 60 (177) the methods of protection at work for women who may be pregnant should provide a standard of protection for any conceptus broadly comparable with that provided for members of the general public.

The necessity of dose limits

If the limit on individual dose (1 mSv per year) will not be applied, a supplemental equivalent-dose limit to the surface of the woman's abdomen of 2 mSv might be changed.

This means that it will be difficult for women to work in controlled areas.

Example from Germany

VGB PowerTech – October 2002

Cost-benefit analysis (CBA): A method for optimizing health physics
Part 1. Fundamental aspects, Revision of the basic paper dated 12 March 1996

Objective and constraints

- preparation of objective, well-founded decisions on taking dose-reducing measures;
- practicable integration in (health physics) plant activities;
- simple applicability;
- quantitative optimisation in consideration of legal requirements;
- matching with the international state of the art.

Scope

This analysis is applicable to all measures and methods that are additionally considered in plant design work for the purpose of reducing the external radiation doses own and third-party personnel are exposed to if collective and individual doses are of a relevant level. Where the collective and individual dose levels persons are exposed to in their work are low and irrelevant, it is neither necessary to make a cost-benefit analysis nor to take specific work-related radiological safety, or dose-reduction measures. Any other necessary optimisation aspects in health physics, e.g. such related to radioactivity entrainment or internal exposure to radiation, are not taken into account in the cost-benefit analysis.

Examples of measures **within the scope of** the cost-benefit analysis:

- mobile shielding;
- stationary shielding;
- decontamination for dose reducing purposes;
- procurement of tools;
- remote control of repair work;
- mechanisation/automation, e.g. of recurrent tests;
- replacement of primary circuit materials;
- alteration of processes and modes of operation;
- optimisation of chemical parameters in the primary circuit.

Examples of measures **outside** the scope of the cost-benefit analysis:

- exposure in the vicinity of the plant;
- decontamination (where not primarily dose-reducing) and air radioactivity control measures;
- personal protection equipment (protective clothing, breathing mask);
- shielding for radiation measuring purposes;
- measures aiming at lowering the probability of event-related radioactivity releases.

Also, any expenditures for “normal” radiological safety measures taken at a plant (for measurement purposes, employee health services, plant monitoring, formal procedures) are not covered by the cost-benefit analysis.

Dose limits

With respect to the individual and collective doses, **lower** limits should be established so as to exclude that irrelevant events are treated in a cost-benefit analysis which are basically meant to be coped with by the “normal” safety measures; such limits can be individually set at the various nuclear power plants. The applicability of the cost-benefit analysis should be considered when, as a minimum, criteria for a “special radiological protection procedure” are given (dose limits as possible criteria: 25 mSv collective dose or 6 mSv individual dose).

In cases of major relevance (dose levels, costs) it may be advisable not to apply the simplified cost-benefit analysis method but, instead, rely on more complex decision-finding techniques.

Integration in plant activities

For the implementation of dose-relevant measures (see **Scope**), the optimisation of radiological protection should be started on at a very early stage (e.g. at the beginning of the “technical clarification” phase).

Maintenance and modification work should be carried out according to a plant specific procedure which includes ALARA elements (see following section on ALARA procedure).

It is within the responsibility of the health physicists to decide on:

- the necessity of applying a formal, non-routine ALARA procedure (i.e. greater involvement of health physicists, documentation) in the planning and implementation of plant activities (the criteria are to be established in dependence of the plant concerned);

- the necessity of a **quantitative** optimisation using the cost-benefit analysis (for criteria for the cost-benefit analysis see **Scope**; review of the method whenever the dose-related criteria for the “special radiological protection procedure” are exceeded).

In case of recurrent plant activities under comparable radiological conditions, a cost-benefit analysis may be left out if so decided by the health physicists.

Simplified cost-benefit analysis

With a view to the power plant activities, the method described herein for individual measures is a major simplification of the “extended cost-benefit analysis” as specified in ICRP 55, Chapter 5.2.2.

α-value

The so-called α-value is an important, plant-independent parameter. It is the reference value by which the reasonability of a considered radiological safety measure is assessed. The α-value is determined from the diagram (see Alpha-value Diagram, below).

For a specific measure, the α-value is determined on the basis of the individual dose range the employees concerned are exposed to. To this end, an individual dose value is estimated which is typical of the groups of employees whose exposure dose is intended to be reduced by the planned measure; a value of α_i is obtained from the diagram for each of these groups. For the entirety of the employee groups, the measure-specific reference α-value is obtained by weighing up with the collective dose portion of the employee group concerned, and summing up:

$$\boldsymbol{\alpha = €150/\mathrm{mSv} \sum \alpha_i \cdot H_i/H}$$

where: α_i α of the respective employee group

H_i/H collective dose portion of the respective employee group.

Thus, the α-values are variables which, though applicable to individual dose-reducing measures, have their common, plant-independent basis in the alpha diagram (see Alpha-value Diagram, below). **In the standard case of a close approximation to the individual dose limits, the alpha diagram will be reduced to a common α base value of €150/mSv**. Shown is also a discretionary bandwidth that takes into account any measure-specific constraints.

Effectiveness of a measure

The effectiveness of a planned radiological protection measure is the cost (in €)-to-benefit ratio (expressed as saved collective dose).

The cost-benefit analysis is carried out in four simple steps as follows

1st step

Determination of the α-value as described in 4.1, where necessary in consideration of the individual dose dependency.

2nd step

Determination of the effectiveness, $\Delta K/\Delta H$, of the measure in question:

ΔK = **Cost needed to save a certain dose**

ΔH Dose saved

3rd step

Comparison of the measure-related effectiveness with the given α-value:

1. $\Delta K/\Delta H \leq \alpha$: Measure is within ALARA range: Indicates usefulness of measure under ALARA aspects.

2. $\Delta K/\Delta H > \alpha$: ALARA range is exceeded as $\Delta K/\Delta H$ increases.

3. $\Delta K/\Delta H$>approx. €15 000/mSv: The considered investment may increase the probability of the occurrence of conventional accidents/ damage; this disadvantage might be greater than the advantage expected to be derived from the radiological protection measure.

4th step

Confirmation of the ALARA result by the health physicist.

As a result of these steps, a recommendation can be given as to how the measure should be taken within the scope of the cost-benefit analysis under health physics aspects.

The inaccuracies inevitably occurring in the determination of $\Delta K/\Delta H$ lead to a corresponding uncertainty of the ALARA result that needs to be taken into account when the final decision is made.

This final decision should be based on the ALARA result and any variables outside the ALARA process that might have a major impact.

5th step

Conventions Quantities ΔK and ΔH for a specific measure – they are to be used in step 2 – are determined as follows:

• investments • operation • decontamination/disposal • assessment of system/total plant use restrictions	including external deliveries/services and own services

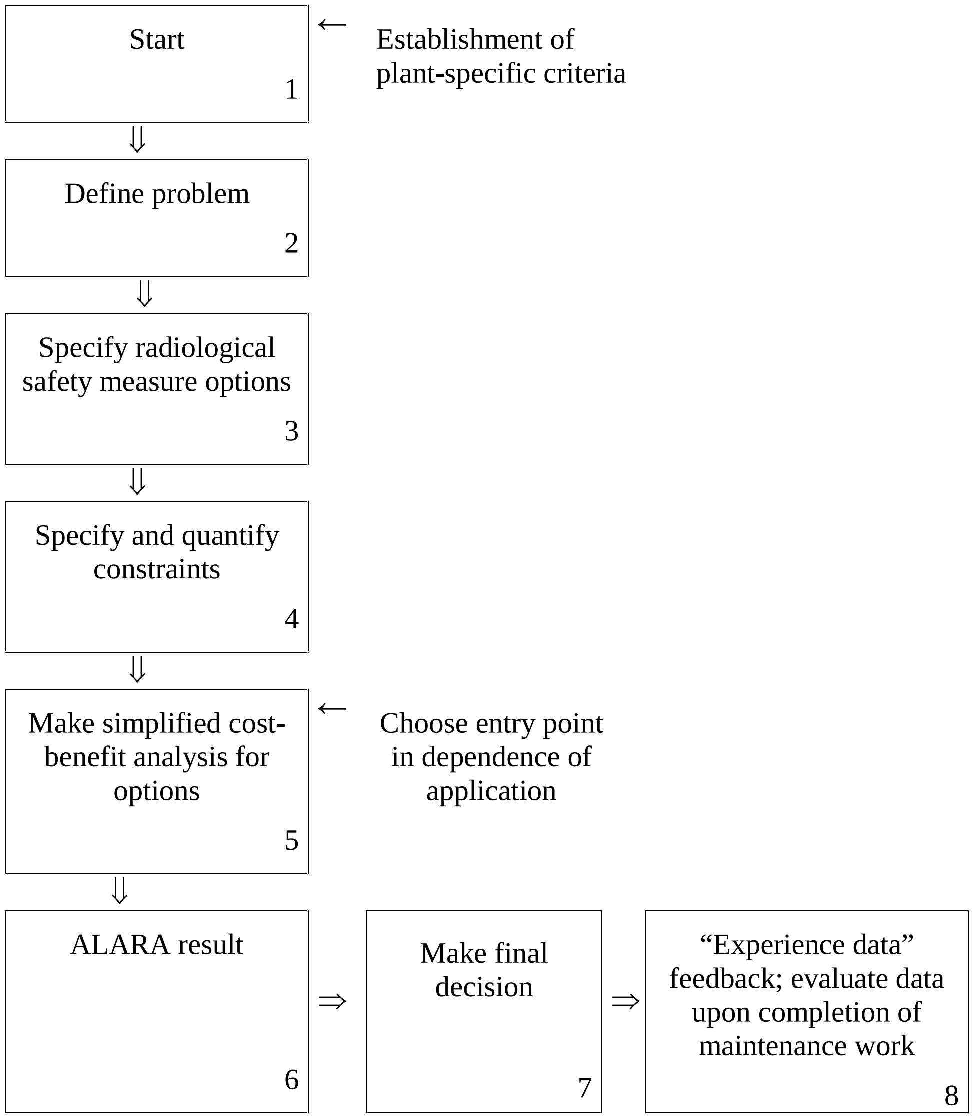
ΔK: Proportionate costs of accruing over the entire period in which the measure is taken, relative to the non-practicability of the measure.

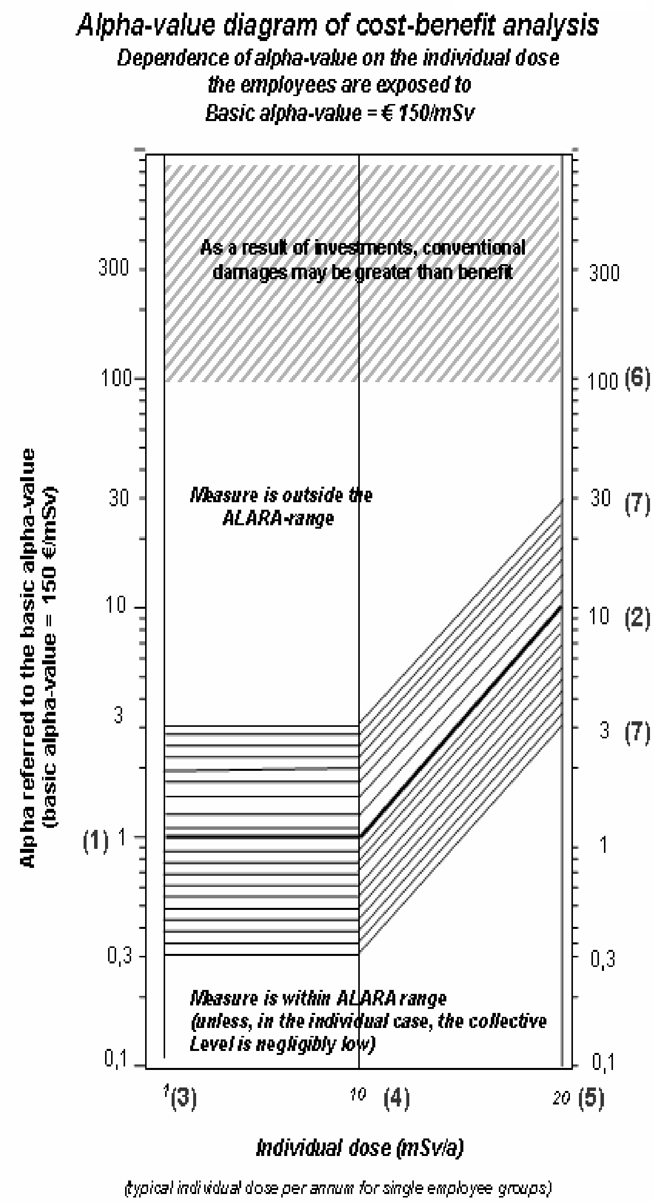
ΔH: Dose saved over the entire period in which the measure is taken, less the dose investment in establishing, carrying out and discontinuing the measure.

The requirement to be met with regard to the accuracy of the input quantities, ΔK and ΔH, is not great. Also, in view of the given uncertainty of the ALARA result obtained, a ΔK/ΔH accuracy of some 10% will do and is covered by the bandwidth as shown in Alpha-value Diagram, below.

ALARA procedure with cost-benefit analysis as applied in planning maintenance work

The ALARA procedure shown below is a logically structured sequence of the jobs to be done. The “simplified cost-benefit analysis” can be included as desired or required.




Alpha-value diagram of cost-benefit analysis
Dependence of alpha-value on the individual dose
the employees are exposed to
Basic alpha-value = € 150/mSv
As a result of investments, conventional
damages may be greater than benefit
Measure is outside the
ALARA-range
Measure is within ALARA range
(unless, in the individual case, the collective
Level is negligibly low)
Alpha referred to the basic alpha-value
(basic alpha-value = 150 €/mSv)
300
100
30
10
3
(1) 1
0,3
0,1
300
100 (6)
30 (7)
10 (2)
3 (7)
1
0,3
0,1
1 (3)
10 (4)
20 (5)
Individual dose (mSv/a)
(typical individual dose per annum for single employee groups)

The following explanatory notes correspond to the figures marked in parentheses in the Alpha-value diagram.

Notes 1 and 2

α-value = basic α-value x factor taken from the diagram;

basic α-value = €150/mSv;

α between 1 and 10 mSv/a individual dose = €150/mSv (= basic α – value);

α between 10 and 20 mSv/a individual dose = α increases to €1 500/mSv.

Derivation basis:

- Costs/benefits of dose-reducing measures taken so far in Germany (without cost-benefit analyses):

  approx. €50 to €2 000/mSv (higher values prevailing with higher individual doses).

- α-values used outside VGB (other countries using nuclear power, other institutions):

  approx. €5 to €2 000/mSv (higher values prevailing with higher individual doses).

- Analogy to insurance industry (Central Europe):

  approx. €10 to €40/mSv, calculated in consideration of a risk factor to ICRP 60.

- Analogy to areas of life outside those in which people are exposed to radiation on account of their job, here e.g. the medical preventive examination sector:

  approx. €10/mSv, calculated in consideration of a risk factor to ICRP 60.

Curve trace 1 – 1 – 10 (= €150 – €150 – €1 500/mSv) is a balanced representation of the various items, with emphasis laid on items a) and b), so that – relative to other areas of life – the radiation risks are considered in the result in a conservative way.

Note 3

If, for a certain plant activity, the “typical individual doses” of all groups concerned are less than 1 mSv/a, the definition of α is no longer applicable, and the cost-benefit analysis can be waived for negligence. Similarly, the cost-benefit analysis can be waived for negligence when the (plant-specific) collective dose is low.

Note 4

The α-value is constant up to 10 mSv/a; this corresponds to an average working life dose based on the limit value of 400 mSv.

Note 5

The α-value increases from an individual dose of 10 mSv/a to a dose of 20 mSv/a. [The 20 mSv/a limit is the maximum mean individual dose based on a limit value of 20 mSv/a or 100 mSv per 5 years (health physics regulations).] The rise is an expression of the growing readiness to invest more in preventing relatively greater risks and to better distribute the risks which the employees are facing.

(It should be noted that radiological safety measures serving **nothing else but** maintaining the individual dose limits for specific activities and specific people, have to be assessed separately and outside the scope of α-value and cost-benefit analysis aspects.)

Note 6

The greater the α-value (as from approx. €15 000 mSv), the more pronounced becomes a negative effect: When a protective measure is taken, the occurrence of conventional accidents needs to be considered. A radiological safety measure becomes unreasonable when the conventional personal injuries to be statistically expected during the implementation of the measure exceed the benefit resulting from a reduction in the (assumed) radiological personal injuries.

Since the expected conventional injury/damage is dependent on the occupational group concerned, there is no distinct α-limit value for this effect. The matter should be given a thought as from €10 000 to €20 000 (irrespective thereof, the measure is outside the ALARA range anyway).

Note 7

The given α-value bandwidth of one magnitude (with a clear emphasis on the logarithmic centre) is indicative of the fact that there is no clear-cut yes/no dividing line for decisions on a planned protective measure; this lack of distinction is also due to the inaccuracies of the “cost” and “dose saved” input quantities.

At the same time, however, the wide band gives (the health physicists) a certain leeway that allows special plant conditions to be considered – although, in general, there is no reason to use different α-values for different plants.

Appendix 7

Old Plant ALARA *versus* New Plant ALARA

Example from the United States

The activity of comparing of nuclear plant ALARA programmes and their results worldwide has been ongoing for decades. The primary metric utilised is collective dose (normally in Sieverts or rem), formulated into various categories as necessary. Such comparisons have proven useful for improving the effectiveness of plants around the world, within countries and states, and even between plants owned by the same company. In addition, regulators have used similar comparisons of ALARA programmes to grade licensee performance at their respective plants.

ALARA assessment at a single nuclear power plant

The assessment of the dose optimisation programme at a single nuclear plant can be seen as a relatively straightforward process when conducted by knowledgeable and experienced personnel, at least on the surface. Such assessments are necessary to determine whether a given plant has a sound programme for optimising individual and collective dose for the full range of activities involving exposure to ionising radiation. The workforce is the ultimate beneficiary. The effort to optimise radiation dose, or to keep doses as low as is reasonably achievable (ALARA), is in fact a fundamental philosophy within radiation protection, and one that plant operators not only strive to achieve, but are required to implement by regulators worldwide.

Below the surface, the assessment of whether a nuclear plant programme is indeed ALARA is anything but simple, but rather a complex process involving the detailed evaluation of a very large number of objective parameters and subjective attributes (See Table 1 for a partial list of areas requiring consideration). With the advent of performing ALARA evaluations in the context of assessing total risk, the process has become even more complex.

ALARA assessment between two similar plants

Since a very large number of parameters must be considered when evaluating a single plant, the problem of evaluating one plant versus another is very complex and difficult at best, even when the two plants are essentially the same (type, design, age, operating characteristics, etc.). Consider the difficulty of comparing two plants that are essentially the same in most respects, have equivalent ALARA programmes, but one plant has a poor plant availability factor coupled with a number of high-dose corrective maintenance jobs chance. If the one plant's operation/maintenance problems are not due to human error, the question is raised as to how the two be directly compared from a dose optimisation standpoint?

Using this example, the task of comparing plants that are the same type, (e.g. PWR) but are different in many respects (layout, age, culture, company, economics), is not only more complex, but is extremely difficult at best. However, often plants that are widely different are compared as if they are the same, with results that may or may not be very meaningful. This is true no matter what entity is performing the inter-comparison, including seasoned regulators. All plant operators and regulators are aware of this dilemma.

One obvious complication is that widely different types of plants, including those with varying regulations, are often compared to each other. In addition, one very specific difference can exist that can greatly complicate this process, that being when a new or somewhat new plant is compared to a much older plant, rendering this effort not only qualitative, but ineffective altogether. Older plants can be faced with operating/maintenance problems, including very high source terms that can greatly increase cumulative dose and thus effect the ALARA programme.

ALARA programme comparisons

In the United States, for example, the Nuclear Regulatory Commission (NRC) requires that a radiation protection programme be in place to ensure that occupational doses are ALARA. However, there are no specific metrics defined to determine if an effective dose reduction programme is being implemented. Part of the challenge stems from the fact that ALARA is an operating philosophy, and not an engineering practice that is strictly defined by discrete measurable parameters. While formal equations have been defined and published internationally and nationally that represent the ALARA concept, it remains open to judgement and is therefore subjective by definition. The ALARA process involves weighing and choosing courses of action based on cost-benefit, that is, optimisation. ALARA is almost always viewed as a continuous improvement process. Most plants utilise continuous improvement planning processes to lay out strategies and tactics to reduce dose.

It is interesting to note that the same comparative activities that have assisted in reducing nuclear plant dose worldwide have also created a dilemma in the comparison of one plant to another when the underlying challenges for dose reduction are not clearly evaluated. This issue often surfaces when new plants are compared to ageing plants, and the comparison of dose ranges from higher overall collective dose to high dose on very specific maintenance or operation tasks.

Since optimisation involves cost versus benefit, capital spent per Sievert (or rem) are established for implementation of the ALARA programme. Dose benefit can be very accurately or reasonably estimated, and costs may be relatively easy to estimate as well. For example, if adding shielding to the control room at a cost of $10K (US) will reduce accumulated dose to the occupants 50 person-rem over the life of the plant ($200 per person-rem) then the decision is an easy one. If that same shielding costs $1M ($20K per person rem avoided) the decision may be more involved.

NRC regulations (10CFR50 App. I) recommends a value of $1K per person-rem avoided to aid in ALARA decision making. While this regulation applies to the design of effluent ventilation and treatment systems, it was used for years for a reasonable value for application to workers. The NRC currently has guidance documents designed for the NRC analysts to use for decision making (policies, proposed actions). The NRC now uses $2K per person rem as the monetary valuation of routine exposure (NUREG/BR-0184, 5.7.4.2 and NUREG-BR-0058, Rev. 3, July 2000). At the same time, almost every plant has selected, using some basis, a value for planning purposes, typically in the $5K to $20K per person-rem avoided range. Therefore, given that the basic cost-benefit monetary valuation varies by at least a factor of 4 between various plants, it is clear that the economics of ALARA is perceived differently by many. Many plants have spent in excess of $25K per person-rem avoided for large projects, in particular repeated recirculation system chemical decontamination in boiling water reactors (BWR). The cost of these activities, including all the costs associated with extended outage time, is as high as the tens of millions of dollars, with quite high costs per avoided person-rem. Plants that have applied those types of costs viewed such expenditure as reasonable to do so. Other plants have viewed such costs as not being ALARA and have not spent such large sums of money.

This illustrates an important question. How can regulators, industry groups and the general public decide when an ALARA programme is effective when there are no precise standards to impose? Should the regulatory agencies for example, downgrade the performance rating of one plant's performance compared to others because they chose not to spend $40K per person rem on a chemical decontamination when existing regulatory guidance suggests the use of a value of $2K for decision making? (Note that it is recognised that the NRC now uses a risk-informed approach in their assessment of licensee activities.)

ALARA evaluations are most frequently *a-priori* processes. Work is pre-planned, then estimates are made of person-hours on the job, estimates of effective dose rates, and estimates of dose rates following dose rate reduction activities all combine to provide what amounts to an educated estimate of data to support ALARA decisions. Since these are estimates, ALARA decisions can only be as good as the estimates. Work tasks can unexpectedly take significantly more or less time than planned. Experienced workers are not available, dose rates are higher than expected, additional scaffolding is needed, tools fail, parts fail, etc. However, the mere existence of the failures of a-priori planning does not always indicate a breakdown in the ALARA programme.

The current state of the US nuclear power industry is that there are almost no plants that are identical. In many cases, even two units at the same site are not the same. Further, as the industry evolves, many modifications that affect dose performance are being implemented. In particular, BWRs are undergoing a rapid evolution in chemistry regimes. Zinc injection, hydrogen injection, condensate pre-filters, noble metals addition, and power up-rates all have the potential to change dose performance, some for the better, while others have an adverse effect. Some of these are very unpredictable (in particular noble metals chemistry addition) and result in significant dose rate impact at some plants and not at others.

The history in the BWR fleet of chemistry-related changes is highly variable. Hydrogen injection can have a greatly varying impact on a plant. Variations in gross injection rate, differences in plant design (jet-pump, non-jet-pump, turbine shielding, etc.), variations in system performance and operational philosophy are all key factors. Zinc injection results vary. For example, some plants have seen as much as a 25% decrease in recirculation system fixed point survey data ("BRAC points") in one cycle after implementing zinc injection, while others had little to none. High iron plants tend to be those with deep bed demineralisers and no filters. Elevated iron affects distribution of dose locations and hot spots when hydrogen is started, and may reduce the effectiveness of chemical decontamination while increasing the mass of contaminants removed. Noble metal additions have in some plants dramatically increased BRAC dose rates, and had little or possibly even a reduction effect in others. Changing chemistry regimes in BWRs and the effect on dose rates is less than predictable in all cases.

Given the high variability in operational history, chemical decontamination efforts, chemistry regimes, and basic plant design, using simple dose results from other plants or indeed from a previous similar task at the same plant for comparison may not be a clear indicator of the ALARA performance or overall performance of a radiation protection programme.

Comparative ALARA – a case study

The Oyster Creek (OC) nuclear station may serve as a strong example of a plant that was subject to long-term comparative ALARA issues. Oyster Creek for many years was consistently the highest dose BWR in the US. Outage dose in the late 1980s was from 1 500 to 2 000 rem. Doses of over 1 rem per day were incurred when the plant was operating. During that period of time, OC was known industry-wide for poor dose performance. In the late 1980s the plant began to show a consistent and dramatic reduction in occupational dose. By the mid-1990s doses were typical of the US BWR fleet, and for two years in the late-1990s, OC was nearly the lowest dose BWR in the US. Total run cycle doses are now at levels consistent with the fleet, although still tending to be on the higher end of the fleet range (but no longer the gross outlier). However, recognition of the dramatic effort and excellent performance needed from a radiation protection/ALARA programme to effect these changes was slow to materialise. Even as these dose reduction feats became apparent, regulators and industry groups were still giving OC weak performance assessments in the RP area.

There are many design differences between OC and most BWRs in the US. Also, the legacy of operational and maintenance history at the plant carried through to compound the radiation protection/ALARA challenge of today. Oyster Creek is a BWR-2, Mark I design plant. The BWR-2 reactor design was used in only two domestic BWRs. This design includes 5 recirculation loops with the attendant 10 pipes, 10 valves, 5 pumps, etc. Later BWR designs use only 2 loops, reducing the number of major pipes and components by a factor of over 2. The lower linear flow rates in the recirculation piping allowed for the potential for more surface deposition in the system. The five-loop design and lack of cross connects compared to the two-loop and ring header design of later BWRs reduced the effectiveness of chemical decontaminations.

Oyster Creek also has a different alloy of stainless (316) in the recirculation piping than other plants. On one level, this was very positive since OC did not have to replace the recirculation piping as did most other BWRs. Such recirculation piping replacements conducted in the early to mid-1980s expended on the order of 1 000 rem. However, since the piping was not replaced, the old piping remained. The replacement piping in other BWRs was fabricated to require fewer welds. This reduces weld inspection scope subsequently, and thus future dose commitment. Some plants installed piping that had been internally polished to reduce surface corrosion layer deposition. This reduced the effective dose rates from the piping in those plants that performed recirculation pipe replacements.

Chemistry control is critical to BWR dose rates. Many plants have filters or filter/demineralisers on the condensate. This dramatically reduces iron oxide input to the reactor system through the condensate/feedwater system compared to the deep bed demineralisers used OC. Oyster Creek was among the first plants to implement hydrogen injection. However, zinc injection was not implemented prior to or at the same time.

The Oyster Creek plant is also a case study in ALARA design. The drywell is very small, about 30 to 50% smaller than later designs. There are three main elevations in the drywell, while most BWR primary containments have 4 or 5. Lack of permanent access levels requires additional scaffolding. There is only one drywell access hatch. All personnel, equipment, used control rod drives (CRD), etc., used this single hatch. Newer BWRs have two main hatches and a CRD hatch.

Equipment was not isolated and separately shielded. The condenser/ feedwater heater bay was located in one large room. There is no separation or shielding between any of the feedwater heaters or the condenser. The main turbine deck had no turbine shielding and is quite narrow. The condensate demineralisers are in one room, and cleanup heat exchangers are all in one room, stacked on top of each other. The spent fuel pool coolers are in the hall next to a stairway, with the pumps mounted immediately below the coolers. The recirculation pumps are not separated by any shield walls, and do not have work access platforms. The drywell equipment drain tank is in the open between two recirculation pumps. The reactor building equipment drain tank is in the same cubicle as two core spray pumps.

A legacy of radiological issues from prior operational history also affected radiological performance at the plant in the late 1980s. In contrast to most BWRs, the vast majority of the reactor building spaces were "contaminated areas", requiring protective clothing virtually to enter any working space in the building. Long-term operational problems in the radwaste processing system had left significant contamination and radiation challenges in the radwaste buildings. Heels in tanks and thick layers of dried sludge on cubicle floors had been left from historical operations. A new radwaste building was built in the 1980s to accommodate processing and reduce dose.

Against this background drastic reductions in measurable parameters began in the late 1980s, outage and operational doses peaked in the early 1980s and began to decrease rapidly throughout the 1990s until doses were reduced by nearly a factor of ten. Personal contamination events decreased, radiological incident investigations decreased by about a factor of ten. The plant operated for nearly 5 straight years without a cited NRC violation in the radiation protection area from 1993-1998. By 1999, plant cycle dose was at the INPO operational dose goal for BWRs. Two of the last four years, OC has been within a few mrem of being the lowest dose BWR in the US.

Comparative ALARA programme issues surfaced in the mid-1990s when all of these improvement efforts were taking place. Subsequently, OC did not receive high performance ratings from the regulator and INPO for the ALARA programme. It is clear that a significant ALARA accomplishment was under-way as evidenced dramatic decreases in plant dose. NRC and INPO perfor-mance ratings still remained lower than the performance would suggest. Repeated attempts to convince the regulator that a different perception was needed were met with resistance, based on low doses found at other US BWRs, many of which were very new plants at that time.

During this period, the regulator indicated that the dose performance had to improve further before a superior ranking would be achieved. Although the comments were never placed into the format of a specific requirement, such as an order (e.g. a backfit) from the NRC or in an agreed commitment from the licensee, it was indicated that the problem was that OC was not doing chemical decontaminations like other plants in the time frame, that therefore source term control was inadequate, and regulatory rankings would not be higher without a system decontamination. The licensee repeatedly evaluated the use of chemical decontamination for source term reduction and dose reduction and concluded that the cost was not warranted for the estimated dose reduction. Chemical decontaminations at the plant would result in costs on the order of $30K per person-rem avoided. Due to the recirculation loop design, chemical decon-tamination would be less effective, cost more, and take longer than at other plants. The use of a non-targeted comparative ALARA approach had convinced the regulator that a chemical decontamination was necessary to show appropriate dose reduction effort. Ultimately, dose rates were stabilised and occupational doses decreased as described above without additional chemical decontaminations.

The ALARA comparisons using same plant job-to-job results during various outages and cycle periods were made by OC. The plant demonstrated to the regulator that refuel floor outage dose decreased successively to 140, 90, and 45 rem. However, regulators stated this would not be considered adequate ALARA success until the dose was reduced to 15 rem, "like other plants".

Lacking clear guidance from international and national standards, the NRC and other regulators have a difficult task in assessing performance at nuclear plants. This is especially true when the plants are faced with very different challenges due their age. Standards can be set that take plant differences into account when evaluating ALARA programmes. Elucidating some of the difficulties in comparing plant ALARA programmes can be included in standards, as well as delineating key parameters that need to be considered, including those parameters having the largest impact on collective dose.

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Table 1

Type of plant

- NSSS (PWR, BWR, Heavy water);
- design layout;
- plant vintage;
- overall age of the plant.

Operation/maintenance

- on-line or off-line refuelling;
- plant capacity factor;
- general plant operating techniques;
- fission product source term;
- activation product source term;
- defective fuel history;
- plant shutdown techniques (including cleanup system configuration and timing);
- plant shutdown chemistry protocols (hydrogen peroxide injection);
- maintenance (corrective, preventative);

- maintenance (at power);
- inspection (routine, ISI);
- source term reduction programme (stellite identification, removal and control);
- reactor water chemistry (including depleted zinc/zinc injection, hydrogen water injection, noble metal chemistry application;
- crud control;
- chemical decontamination of systems and major components (full/ partial system);
- periodic plant decontamination;
- major component replacement (e.g., recirculation piping, steam generator replacement);
- major system capability-dose contributors (e.g., reactor water cleanup system flowrate);
- radwaste system operation (use of special resins, filters);
- hot-spot reduction programme (flushing, hydrolasing);
- shielding programme (permanent and temporary);
- permanent platform/scaffolding programme;
- high-dose jobs;
- high-collective dose (from low-dose activities);
- robotics;
- remote handling capability;
- dose monitoring and tracking;
- trend analysis and lessons learned (including sound follow-up);
- work management (planning, control, scheduling, and implementtation).

Culture

- plant culture;
- senior management culture;

- worker culture;
- safety culture;
- radiation Protection priorities;
- excellence programmes;
- suggestion programmes;
- incentive programmes;
- ALARA Committees;
- third party inspections/peer-reviews (other plants, WANO, INPO);
- benchmarking;
- use of available ALARA resources (ISOE, WANO, INPO, EPRI, NSSS ALARA owners groups, vendors, and intra/inter-company).

Economics

- country and company economics;
- cyclic company economics;
- economy of scale (multiple unit sites or companies);
- resource sharing between companies;
- sub-optimisation of ALARA efforts.

(Note: this list is not meant to be "all-inclusive")

Appendix 8

Optimisation in Decommissioning

Example from the United States

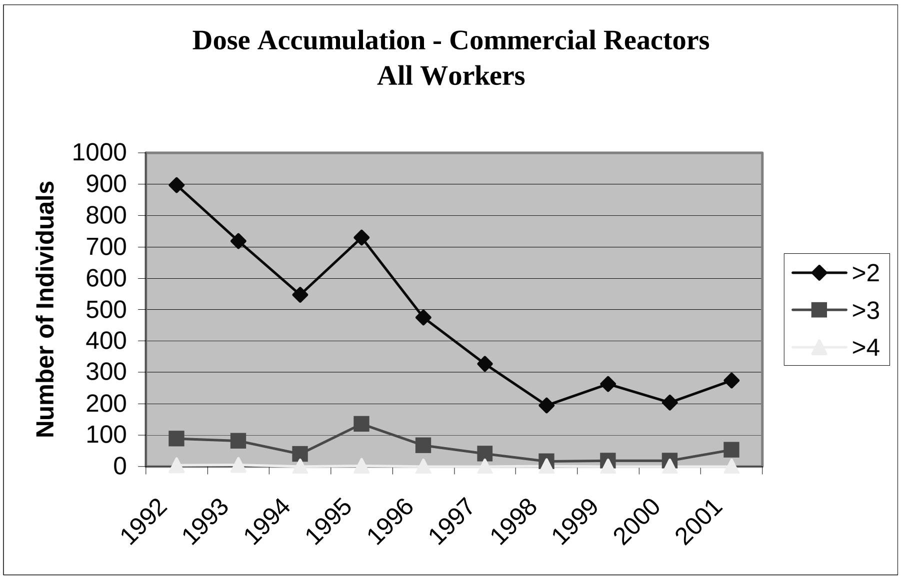
For decommissioning projects, there are two different areas that would be affected by a proposed reduction in dose limits. The first is an impact on occupational workers and the second is a potential impact on license termination due to reduced public dose limits.

Workers who are responsible for the tasks involved in a major nuclear power plant decommissioning project conduct activities that range from highly technical cutting processes (such as the segmentation of reactor internals) to very non-technical work such as the demolition of concrete structures using pneumatic jackhammers. The technical work is typically conducted by a small group of highly trained contractors. These people are limited in numbers and often travel from one facility to another. Currently there are a number of active decommissioning projects in the United States. At this time, none of those plants has had difficulty meeting the 50 mSv/yr (5 rem/yr) regulatory limit for occupational exposure. However, there have been instances where transient workers (contractors) did receive annual radiation exposures that approached 30 mSv (3 rem). Those individuals included specialty contractors, radiation protection technicians and other specialised workers. Overall, with sufficient radioactive decay in the power plant (the average is about ten years between permanent shutdown and the onset of active decommissioning) the radiation exposure levels are typically low enough so that occupational dose limits are not often approached. However, an occupational dose limit of 20 mSv/yr would adversely affect the ability of some specialty workers to complete their jobs. Replacement of these individuals by others with less experience could adversely impact both personnel safety and success of the project. Moreover, it has been often demonstrated that collective exposures increase when less experienced workers are utilised.

Note also that a reduction in dose limits has a cascading effect on the actual dose that may be received. This is due to the licensees’ need for conservatism to avoid reaching or exceeding a regulatory limit. For example, if the dose limit were reduced to 20 mSv/yr (2 rem/yr), most licensees would adopt an administrative control level of somewhere between 15 and 18 mSv/yr (1.5 to 1.8 rem/yr). The application of conservative ratios for personal electronic dosimeters (PEDs) to dose of record devices (TLDs for instance) drives the effective limit even lower. Finally, the radiation safety technicians in the field will apply their own conservatism (typically 80%) to control mechanisms such as stay time to avoid exceeding the administrative control level. All of these factors result in an effective dose limit closer to 10 mSv/yr (1 rem/yr) than the desired 20 mSv/yr (2 rem/yr).

The graph below indicates that there are hundreds of workers who receive greater than 20 mSv/yr and many dozens who receive greater than 30 mSv/yr. Those workers would be adversely affected by a proposed dose limit of 20 mSv/yr. The majority of the workers who exceed 20 and 30 mSv/yr levels are transient workers (contractors). Note that their numbers have actually increased in the most recent year of record.

Figure 1. Dose Accumulation (in rem) at US Commercial Power Reactors
(US Nuclear Regulatory Commission NUREG-0713 reports)



The second area impacted by reduced dose limits would be the acceptable endpoint for decommissioning due to public dose. In the United States, the acceptance criterion for terminating a radioactive materials license is

0.25 mSv/yr (25 mrem/yr) to a member of the “critical group.” Above and beyond that criterion, the licensee must apply the optimisation process so that the residual radioactivity is reduced to ALARA. While it is unlikely that any nuclear power plant decommissioning project will finish with a public dose estimate near the upper limit of 0.25 mSv/yr, any possible reduction in public dose limits must recognise that limits much lower than 0.25 mSv/yr drive the detection criteria for some radionuclides below what is either achievable or measurable. In other words, for an acceptance criterion of 0.25 mSv/yr, some radionuclides might be just barely detectable using standard instrumentation. A lower limit would not be detectable. Therefore the licensee would have the impossible task of proving that the radionuclide was not present at levels below that capable of detection. The ICRP must recognise that the optimisation process is adequate to ensure public health and safety when the limit is on the order of 0.25 mSv/yr (or 0.3 mSv/yr for the proper increment of background), but for the next increment down of 0.03 mSv/yr (3 mrem/yr), it would be impossible to prove compliance.

Example

The screening values for license termination were published in an Appendix C to NUREG-1727, “NMSS Decommissioning Standard Review Plan”, US Nuclear Regulatory Commission, 2000. Those screening values are based on conservative assumptions regarding public exposure pathways and on the acceptance criterion of 25 mrem/yr or 0.25 mSv/yr. The table below lists the surface soil contamination screening values for some radionuclides that might be found in nuclear power plant decommissioning:

Radionuclide	**Screening Value (pCi/g) NUREG-1727**	**Screening Value (Bq/g)**
^{60}Co	3.8	0.140
^{137}Cs	11.0	0.410
^{241}Am	2.1	0.078

A Final Status Survey requires scanning of 100% of areas that have had contamination remediated in addition to sampling those areas and analyzing the samples to very low levels (see NUREG-1575, “Multi-Agency Radiation Survey and Site Investigation Manual (MARSSIM)”, US Nuclear Regulatory Commission, 1997). The table below compares the Screening Values to the

Scan MDC values (minimum detectable concentration) calculated according to the concepts in MARSSIM and converting to international units:

Radionuclide	**Screening Value NUREG-1727 (Bq/kg)**	**Scan MDC (Bq/kg)**
^{60}Co	140	215
^{137}Cs	410	385
^{241}Am	78	1 650

According to MARSSIM, the Scan MDC for survey instruments should meet or exceed (be smaller in magnitude) than that the derived concentration guideline level (DCGL) in order to avoid having to make further adjustments using area factors. For DCGL's equal to the Screening Values (equivalent to 0.25 mSv/yr), examination of the table above shows that only for ^{137}Cs is the Scan MDC below the Screening Value. For the other two radionuclides, ^{60}Co and ^{241}Am, the Scan MDC exceeds the Screening Value. The end result is that, for these two radionuclides, significant adjustments must be made to the number of samples taken. This is not a difficult task for ^{60}Co, but may be expensive for a large area under consideration due to the greatly increased number of samples that must be analysed by the laboratory.

If the acceptance criterion is reduced, for example from 0.25 mSv/y (25 mrem/y) to 0.03 mSv/y (3 mrem/y) as has been discussed, the screening values are reduced proportionately. The respective values would be: 17, 49, and 9.4 Bq/kg for ^{60}Co, ^{137}Cs, and ^{241}Am respectively. Clearly those values are so far below the Scan MDC's that conducting the final status survey for license termination would be very difficult and expensive.

For a radionuclide like ^{241}Am, the ability to detect the radionuclide at a level like 9.4 Bq/kg may be problematic. Uranium and transuranic radionuclides such as plutonium may be even more difficult to detect using laboratory analyses of samples, simply because as alpha-emitters, instrument sensitivity is limited. Scaling or use of surrogates might be possible at some facilities but at fuel cycle facilities where gamma-emitters may not be present, these radionuclides may be impossible to detect if the acceptance criterion is too low (e.g. 0.03 mSv/yr).