Radiological Protection
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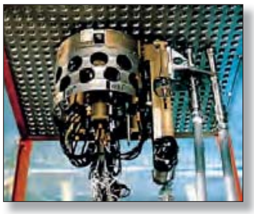
# Work Management to Optimise Occupational Radiological Protection at Nuclear Power Plants



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# Work Management to Optimise Occupational Radiological Protection at Nuclear Power Plants


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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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## NUCLEAR ENERGY AGENCY

The OECD Nuclear Energy Agency (NEA) was established on 1st February 1958 under the name of the OEEC European Nuclear Energy Agency. It received its present designation on 20th April 1972, when Japan became its first non-European full member. NEA membership today consists of 28 OECD member countries: Australia, Austria, Belgium, Canada, the Czech Republic, Denmark, Finland, France, Germany, Greece, Hungary, Iceland, Ireland, Italy, Japan, Luxembourg, Mexico, the Netherlands, Norway, Portugal, Republic of Korea, the Slovak Republic, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The Commission of the European Communities also takes part in the work of the Agency.

The mission of the NEA is:

- to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- 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. In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

Corrigenda to OECD publications may be found on line at: *www.oecd.org/publishing/corrigenda*.

# FOREWORD

Since 1992, the Information System on Occupational Exposure (ISOE) has provided a forum for radiological protection professionals from nuclear power utilities and national regulatory authorities worldwide to discuss, promote and co-ordinate international co-operative undertakings for the radiological protection of workers at nuclear power plants. The ISOE objective is to improve occupational exposure management at nuclear power plants by exchanging relevant information, data and experience on methods to optimise occupational radiological protection.

Key to successful occupational exposure management is the careful planning and execution of jobs at nuclear power plants, referred to as work management. Work management stresses the importance of approaching jobs from a multi-disciplinary team perspective, and of following jobs completely through all stages of work. By focusing such attention on the jobs to be undertaken, their successful completion can be assured – on schedule, within budget, fulfilling the desired goal and optimised from the perspective of occupational radiological protection.

Since the publication of the first ISOE report on work management in 1997, this approach has been broadly implemented in the nuclear power industry worldwide, and for several years has shown itself to be useful in reducing both occupational doses and operational costs. However, economic and regulatory pressures have continued to confront the nuclear power industry, while many other changes have also arisen, including evolutions in the system of radiological protection, technological advances, social, political and economic situations, and the prospects for new nuclear build. Of no less importance is the ongoing exchange of experience amongst radiological protection professionals. These collective challenges and experiences have provided a deep base of practical knowledge from which to reconsider work management in the first part of the 21st century.

This updated report on work management provides practical guidance on the application of work management principles as a contribution to the optimisation of occupational radiation protection. It recognises that while work management is no longer a new concept, continued efforts are needed to ensure that good performance, outcomes and trends are maintained in the face of current and future challenges. The focus of this report is therefore on presenting the key aspects of work management that should be considered by management and workers to save time, doses and money, supported by updated practical examples from within the ISOE community.

ISOE is jointly sponsored by the OECD Nuclear Energy Agency and the International Atomic Energy Agency.

ISOE Network: www.isoe-network.net

## ACKNOWLEDGEMENTS

This report on work management was approved by the ISOE Management Board following its development by the ISOE Expert Group on Work Management (EGWM). The Expert Group consisted of the following members:

| | |
|---|---|
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| Mr. S. Zorrilla | Laguna Verde NPP, Mexico |

The EGWM gratefully acknowledges the contribution of the many ISOE members who provided practical examples of work management in their local radiation protection programmes, as well as the authors of presentations presented at previous ISOE international and regional ALARA Symposium, from which additional examples have been drawn. These presentations can be found on the ISOE Network website (www.isoe-network.net).

The EGWM hopes that the dissemination of this "Green Book" on work management will foster the optimisation of occupational radiation protection and the reduction of worker exposures both within current plants as well as in future plants.

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# 1. INTRODUCTION

## 1.1 Background

Nuclear plants are constructed to high engineering standards, operated by highly trained and licensed operators and independently assessed by government regulatory authorities. A mandate of error-free performance is essential for safety, efficiency and public acceptance of nuclear plant technology.

The nuclear industry in the 1960s and 1970s was characterised by rapid expansion of nuclear powered electricity generation plants as an alternative to large-scale coal and gas powered plants. However, at the end of the 1970s and in the 1980s, the accidents at Three Mile Island Unit 2 and Chernobyl decelerated the push toward nuclear power in many countries. In response to this situation and the absence of expansion, the 1980s were to a large extent focused on improving the safety of the existing fleet of operating reactor units.

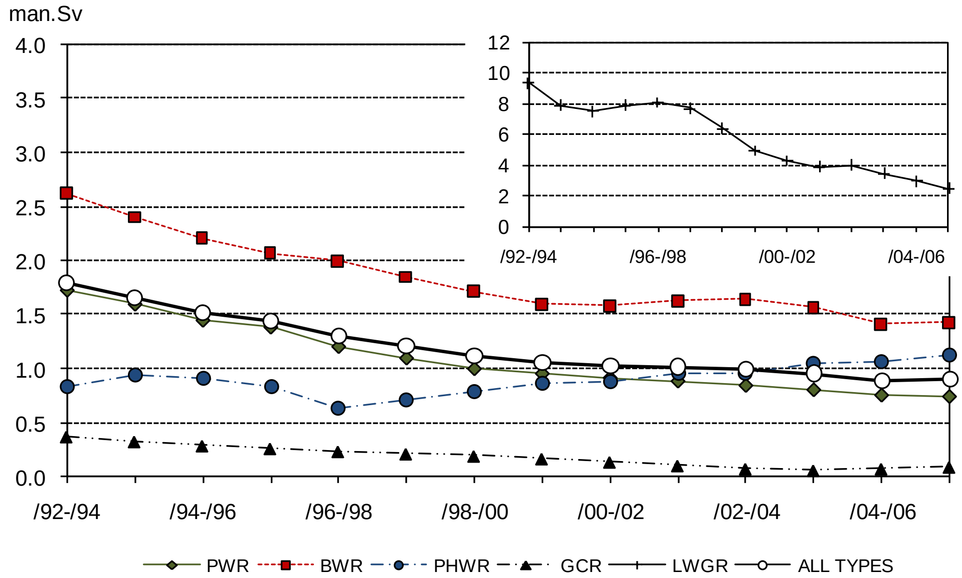
In many countries, the 1990s prepared nuclear utilities for deregulation in the electricity industry. The US nuclear industry, for example, benchmarked their activities and performance against European work management practices in seeking safer and more efficient means to operate and refuel nuclear units and increase annual capacity factors. By 2000, the nuclear industry in some countries had become very robust in their ability to execute shorter and more effective refuelling and maintenance outages, all while improving the optimisation of occupational radiation protection. In the US alone, capacity factors rose from 80% in the 1970s and 1980s to about 90% in the 1990s. This was done while decreasing exposures to workers throughout the nuclear industry.

As a result, throughout the world, occupational exposures at nuclear power plants have steadily decreased since the early 1990s. Regulatory pressures, technological advances, improved plant designs and operational procedures, ALARA culture and information exchange have contributed to this downward trend (Figure 1). However, with the continued ageing and possible life extensions of nuclear power plants worldwide, ongoing economic pressures, regulatory, social and political evolutions, and the potential of new nuclear build, the task of ensuring that occupational exposures are As Low As Reasonably Achievable (ALARA), taking into account operational costs and social factors, continues to present challenges to radiation protection professionals.

Since 1992, the Information System on Occupational Exposure (ISOE), jointly sponsored by the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA), has provided a forum for radiological protection professionals from nuclear power utilities and national regulatory authorities worldwide to discuss, promote and co-ordinate international co-operative undertakings for the radiological protection of workers at nuclear power plants (see Appendix 1). The objective of ISOE is to improve the management of occupational exposures at nuclear power plants by exchanging broad and regularly updated information, data and experience on methods to optimise occupational radiation protection.

To this end, ISOE includes a global occupational exposure data collection and analysis programme, culminating in the world's largest occupational exposure database for nuclear power plants, and a communications network for sharing dose reduction information and experience amongst participants. These resources, including access to the ISOE Network information exchange website (www.isoe-network.net) are available to participants of the ISOE programme.[1]

Figure 1. **3-year rolling average per reactor for operating reactors in ISOE, 1992-2007 (man·Sv)**




(Source: ISOE, 2008)

Key to the successes noted above has been the widespread understanding of the importance of careful planning and execution of refuelling and maintenance outages at nuclear power plants. The first ISOE report on *Work Management in the Nuclear Power Industry* (NEA, 1997) was an important report in this regard. Its timely content was aligned with the focus in the nuclear industry, which was under pressure to achieve production goals with significantly smaller operating and technical staff. In short time, the report became a guide which attracted a keen interest from radiation protection managers, plant managers and senior managers. That report, built upon the first few years of ISOE experience, was an important contribution to the optimisation of occupational radiation protection in the nuclear industry at a time when the principles of work management had not yet been fully integrated into routine work practices.

Work management stresses the importance of approaching jobs from a multi-disciplinary team perspective, and of following jobs completely through the stages of conception, design, planning, preparation, implementation and follow-up. By focusing such attention on the jobs to be undertaken, their successful completion can be assured – on schedule, within budget, with a sufficient level of quality and maximum chance of fulfilling the originally desired goal, and optimised from the perspective of occupational radiological protection.

Work management is now broadly implemented in the nuclear power industry worldwide, and for several years has shown itself to be useful in reducing both occupational doses and operational costs. However, economic and regulatory pressures have continued to confront the nuclear power industry, while many other changes have also arisen, including evolutions in the system of radiological protection, technological advances, social, political and economic changes, and the prospect of new nuclear build. Of no less importance is the ongoing exchange of information and experience amongst

1. Official participants to ISOE include those nuclear electricity utilities and national regulatory authorities that participate in ISOE under the ISOE Terms and Conditions.

radiation protection professionals from nuclear power utilities and national regulatory authorities worldwide. These collective challenges and experience have provided a deep base of practical knowledge from which to reconsider work management in the first part of the 21st century.

Recognising both the broad use that the first work management report has had amongst radiation protection professionals over the past 10 years, as well as the changing work environment since its publication, the ISOE Management Board, in response to a proposal from the ISOE Asian Technical Centre, launched the ISOE Expert Group on Work Management (EGWM) in 2007 to develop an updated report reflecting the current state of knowledge, technology and experience in occupational radiation protection of workers at nuclear power plants.

As with the 1997 report, the objective of this current report on "Work Management to Optimise Occupational Radiation Protection in the Nuclear Power Industry" is to provide practical guidance on the application of work management principles as a contribution to the optimisation of occupational radiation protection. This recognises that while work management is no longer a new concept, continued efforts are needed to ensure that good performance, outcomes and trends are maintained in the face of current and future challenges. The focus of this report is therefore on presenting the key aspects of work management that should be considered by management and workers to save time, dose and money, supported by updated practical examples from within the ISOE community. The EGWM hopes that this approach will bring practical value to the reader and encourage continuous improvement of performance.

## 1.2 Principles of work management

The operation and maintenance of nuclear power plants imply the occupational exposure of workers. However, experience has shown that a coherent and comprehensive work management approach, in addition to contributing to good radiation protection, also facilitates safe and economic plant operation.

Work management, as presented in this report, is a comprehensive methodology which stresses the importance of managing jobs completely from planning to follow-up using a multi-disciplinary team approach which involves all relevant stakeholders. While dose reduction is only one component of this approach, radiation protection personnel at nuclear power plants are a key component within such teams, and must operate within this context to ensure that occupational exposures are kept ALARA.

The determining factors in occupational exposure in nuclear power plants are the radiation levels in work areas, the amount of time spent in these areas and the number of workers involved. These factors can be influenced by both technical as well as administrative measures. Dose reduction is often accomplished through reductions in the source term, the number of workers in the controlled area, the time spent by workers in that zone and the amount of rework required (due to faulty design, equipment or work).

Work management measures aim at optimising occupational radiation protection in the context of the economic viability of the installation. If properly applied, work management will lead to a reduction of occupational exposures in an ALARA fashion. Thus, the goals of reducing cost as well as classical safety risks and of minimising the time required for an outage can often be simultaneously fulfilled. In brief, the effective application of work management principles should save time, dose and money. Important factors in this respect are those measures, methods and techniques influencing:

- Dose and dose rate, including source-term reduction.
- Exposure, including amount of time spent in controlled areas for operations, maintenance, inspection and repair work.
- Efficiency in work planning, including short- and long-term planning, worker involvement, co-ordination of activities, training and information.

Equally important due to their broad, cross-cutting nature is the influence of motivational and organisational arrangements on the effectiveness of work management approaches. The responsibility for the previously mentioned aspects may reside in various parts of an installation's organisational structure. Thus, the multi-disciplinary nature of work management must be recognised, accounted for and well-integrated in any work.

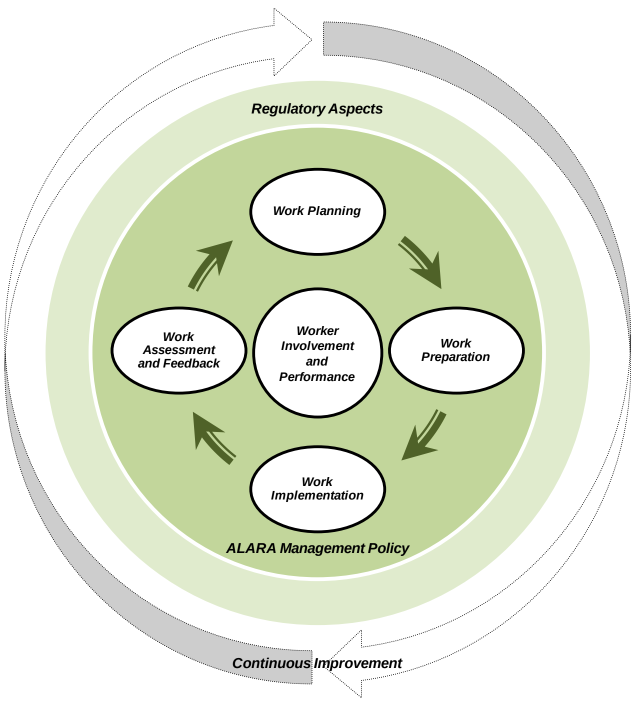
This book provides practical guidance based on the operational experience within the ISOE programme in the key areas of work management to optimise occupational radiation protection, including:

- Regulatory aspects.
- ALARA management policy.
- Worker involvement and performance.
- Work planning and scheduling.
- Work preparation.
- Work implementation.
- Work assessment and feedback.

The specific aspects of work management applicable to each of these areas are illustrated by examples and case studies arising from ISOE experience. The topics and practical examples presented are intended to provide all those involved in work management with relevant experience on good practice in the implementation of work management initiatives aimed at optimising occupational radiation protection in the nuclear power industry.

Work management is a comprehensive and iterative approach to work. The philosophy of work management is a continuous loop that consists of planning and scheduling, preparation, implementation, assessment and follow-up in order to make the overall work progressively optimised (Figure 2). Feedback is a key component, and such feedback should be obtained both locally and globally. Assessment and feedback is the final stage of work and, at the same time, the first stage of the process. However, work management is also forward looking. Therefore, recognising the constant evolution of many parameters that are included in the above topics, such as ongoing technological advances, as well as using past and current lessons to not only inform future work but also future design and operations, this report closes with a chapter on "Ensuring Continuous Improvement".

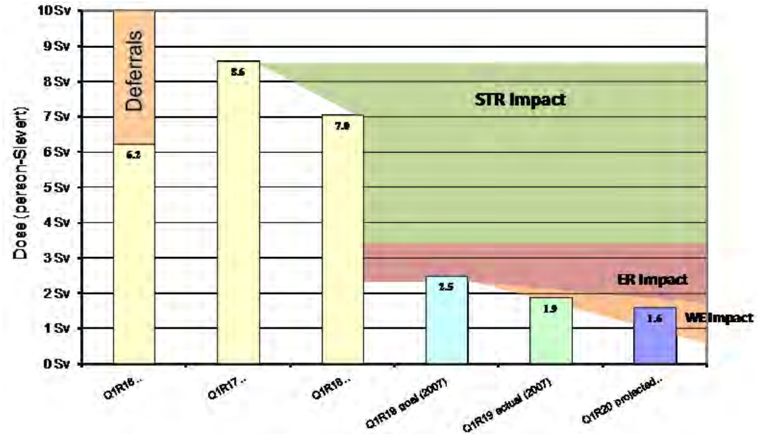
Figure 2. **Work management elements and their iterative nature**



***United States: An example of work management (Organisational ALARA) at Quad Cities NPP***

Quad Cities-1 NPP successfully reduced collective radiation exposure (CRE) through an integrated approach focusing on all components of work management (or organisational ALARA). Concerted efforts addressing source term reduction (STR), equipment reliability (ER), worker engagement (WE) and strategic planning have decreased CRE to 1.9 person·Sv for the 2007 refuelling outage from a high of 8.6 person·Sv for the 2002 refuelling outage due to challenges created by chemistry transients affecting primary and secondary piping dose rates and by equipment challenges associated with the up-rating of the units. Aggressive application in each of these areas has also reduced on-line CRE by 70%.

**Quad cities-1 (Outage CRE)**



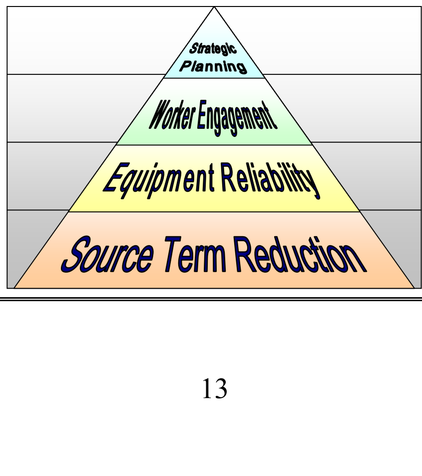

Successful actions by area include:

*Source term reduction:* Chemical decontaminations of recirculation piping and moisture separators; replacement of turbine blades containing Stellite-based erosion shields; use of a Site Exposure Reduction Charter with Site Vice-President signature approval/accountability; integration of chemistry parameters into site management vocabulary and daily discussion; operational focus on water chemistry; and focus on beating minimum industry guidance and achieving best-identified performance for measures such as Cobalt-to-Zinc ratio.

*Equipment reliability:* Power uprate recovery to treat plant vibrations through effective diagnosis and treatment of underlying causes; implementation of the acoustic side branch modification on steam lines to resolve a 30+ year old vibration issue, reducing equipment failure dramatically (vibrations now less than 50% of those at old full power); steam dryer replacement increased capacity in concert with the uprated power; development of technical human performance philosophy and principles governing engineering activities that include exposure concerns; including dose as a required value in Plant Health Committee discussions of modification prioritisation; and integration of dose into equipment reliability priority lists.

*Worker engagement:* Individual dose accountability established, including individual daily dose goals; Radiation Work Permit trip tickets implemented, forcing determination and accounting of dose individually by entry; First Line Supervision ownership of crew performance and feedback; and Management accountable to 10 microSv (1 mrem) overages in "Plan of the Day" management meetings.

*Strategic planning:* Fleet dose now monitored accounting for aggregate over/under performance; Corporate ALARA Committee established with site ownership for dose at the Plant Manager level accountable to the Senior Vice President of Operations; and long-term planning includes dose impact of future jobs (out 5 years) as part of decision-making process.



# 2. REGULATORY ASPECTS

*The main principles of radiation protection (justification, optimisation of radiation protection and limitation of individual doses) are established at the international level. National regulations are elaborated to provide a radiological protection framework consistent with these principles. Within this framework, utilities should also develop and set their own internal procedures and develop targets to manage individual and collective exposures on a case by case basis.*

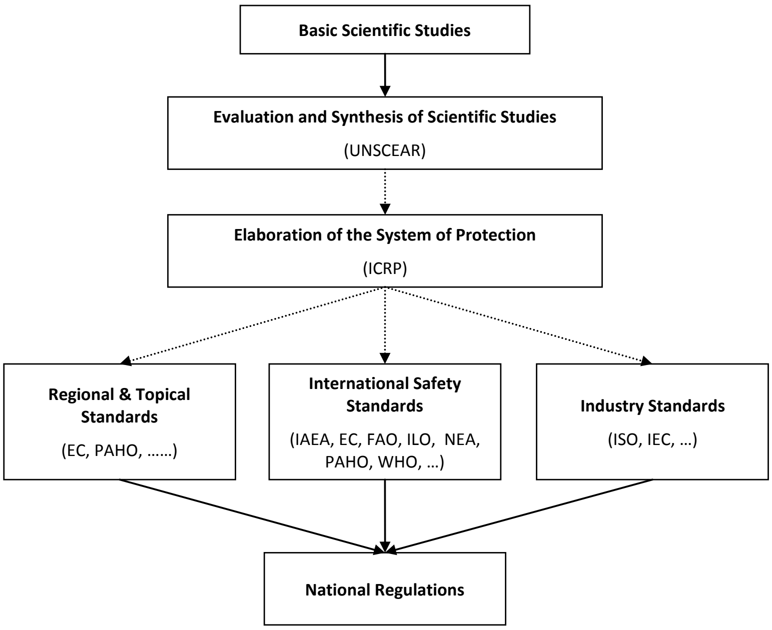
## 2.1 Introduction

While it is the licensee's duty, in the first instance, to ensure that a particular operation is safe from the perspective of nuclear safety and radiological protection, this must be done within the applicable regulatory framework. Regulatory frameworks aim to secure the maintenance and improvement of safety at civil nuclear installations through regulations addressing nuclear safety, and ensure the protection of workers, public and environment from ionising radiation through regulations addressing radiation protection. Such regulation provides for an effective radiological protection infrastructure which includes a "safety culture" shared by those with protection responsibilities from workers through to management. The licensing regime therefore provides one of the means of control available to a regulatory authority. Such regimes can vary in their level of prescription and can therefore impact the options available to utilities within their approaches to work management. This chapter briefly discusses international radiological standards and guidance and the means by which they are implemented within the regulatory frameworks of individual countries.

## 2.2 International standards and guidance

Several international organisations contribute significantly to the establishment of the scientific and legal framework in the field of radiological protection, and thus have a major bearing on the safety standards adopted nationally to manage work at nuclear installations. Although there is no process formally defined, these include the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), the International Commission on Radiological Protection (ICRP), the International Atomic Energy Agency (IAEA), the European Commission (through the EURATOM Treaty), and the OECD Nuclear Energy Agency (NEA). In addition, other inter-governmental and non-governmental organisations and programmes have also provided feedback and guidance relevant to the elaboration of new standards. The roles of these bodies in establishing the radiological protection framework are discussed below (Figure 3).

Figure 3. **Elaboration of radiation protection standards and regulations**[2]




***United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR)***

UNSCEAR was established in 1955 by the United Nations to collect and evaluate information on the levels and effects of ionising radiation used for peaceful as well as military purposes, and arising from natural and man-made sources. Governments and organisations throughout the world rely on UNSCEAR estimates as the scientific basis for evaluating radiation risk and for establishing protective measures.

UNSCEAR systematically reviews and evaluates global and regional levels and trends of occupational, public and medical exposure. It also regularly evaluates the evidence for radiation-induced health effects from studies of the survivors of the atomic bombings in Japan and other exposed groups, as well as advances in scientific understanding of the mechanisms by which radiation-induced health effects can occur. These assessments (e.g. UNSCEAR, 2000, 2001, 2006) have provided the scientific foundation used by the ICRP in developing its radiological protection recommendations, and by the relevant agencies in the UN system in formulating international radiological protection standards.

***International Commission on Radiological Protection (ICRP)***

The ICRP is a non-governmental scientific organisation established in 1928 by the 2nd International Congress of Radiology. It is regarded as the world's foremost body on radiological protection, issuing recommendations from time to time on which standards and guidance within the radiological protection field as a whole can be based. ICRP authority stems from the standing of its independent members who are drawn from a range of scientific disciplines and from the merit of its recommendations.

ICRP recommendations for limiting the detrimental effects of ionising radiation are issued in publications and through subsequent statements clarifying or extending those recommendations. For more than 50 years, ICRP recommendations have been the basis of underlying international and national

2. EC: European Commission; FAO: Food and Agriculture Organization of the United Nations; IEC: International Electrotechnical Commission; ILO: International Labour Organisation; ISO: International Organization for Standardization; PAHO: Pan-American Health Organization; WHO: World Health Organization.

standards and principles governing the use of ionising radiation. At the end of 2007, ICRP issued new general recommendations in Publication 103 (ICRP, 2007), resulting from an extensive drafting and consultation process. Publication 103 formally replaces the previous ICRP general recommendations issued in 1990 as Publication 60 (ICRP, 1991). As of the time of publication of this report, most international standards and national regulations are based on ICRP Publication 60.

*The ICRP system of radiological protection*

The three basic principles which form the basis for radiological protection standards and regulations worldwide as elaborated by the ICRP in Publication 60 and reiterated in Publication 103 are:

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

The major features of the new general recommendations, which consolidate and add to previous recommendations issued by ICRP since Publication 60 are as follows (ICRP, 2007):

- Maintaining the three fundamental principles of radiological protection and clarifying how they apply to radiation sources delivering exposure and to individuals receiving exposure.
- Updating the radiation and tissue weighting factors, and the radiation detriment based on the latest available scientific information.
- Evolving from the previous process-based protection approach of practices and interventions by moving to a situation-based approach characterised as planned, emergency, and existing exposure situations, and applying the fundamental principles of justification and optimisation of protection to all controllable exposure situations.
- Maintaining the individual dose limits for effective dose and equivalent dose from all regulated sources in planned exposure situations.
- Re-enforcing the principle of optimisation of protection, which should be applicable in a similar way to all exposure situations, with restrictions on individual doses and risks (dose and risk constraints for planned exposure situations; reference levels for emergency and existing exposure situations).
- Including an approach for developing a framework to demonstrate radiological protection of the environment.

Dose limits: in addition to reaffirming the three basic principles of radiological protection, the new ICRP general recommendation have maintained the dose limits as previously defined in Publication 60. For occupational exposure in planned exposure situations, ICRP recommends that the limit be expressed as an effective dose of 20 mSv/year, averaged over defined 5 year periods (100 mSv in 5 years), with the further provision that the effective dose should not exceed 50 mSv in any single year (ICRP, 2007). Both the 1996 International Basic Safety Standards (IAEA, 1996) as well as the 1996 EURATOM Basic Safety Standards (EURATOM, 1996) express the individual dose limit as 100 mSv/5 years, with a maximum of 50 mSv in one single year.[3]

3. Both the 1996 International Basic Safety Standards and the EURATOM Basic Safety Standards were in the process of revision at the time of publication of this report.

Optimisation: the practical implementation of optimisation means that the level of radiological protection should be the best under the prevailing circumstances, maximising the margin of benefit over harm. The ICRP has recommended that in order to avoid inequity in the distribution of individual doses resulting from an optimisation procedure, there should be source-related restrictions on the doses to individuals which are referred to as dose constraints. For occupational exposures, a dose constraint is a value of individual dose used to limit the range of options in the optimisation process, such that only those expected to result in doses below the constraint are considered (ICRP, 2007). The dose constraint is not a regulatory limit; however if exceeded, protective actions should be reviewed and modified if appropriate. The principle of optimisation of radiation protection is further developed in ICRP Publication 101 (ICRP, 2006).

***International Atomic Energy Agency (IAEA)***

The IAEA was formed in 1957 as an independent, inter-governmental organisation within the United Nations network. Its main objective is to promote atomic energy in the interests of peace, health and prosperity throughout the world. In the context of the international system of radiological protection, the IAEA plays a special role in establishing international safety standards, codes and guides representing international consensus.

Some IAEA standards, by nature of their broad scope and applicability, are co-sponsored by other international, intergovernmental organisations to avoid duplication of efforts and to prevent the issuing of contradictory standards. The 1996 IAEA "International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources" (BSS) were co-sponsored by six international organisations,[4] helping to ensure the very broad use of the BSS by various international governmental organisations and their national constituencies. The 1996 BSS is based largely on the radiation protection principles elaborated in ICRP Publication 60. While not mandatory on any country, most of the IAEA Member States have today integrated the International BSS into their national laws, or are consistent with the provisions therein.

In view of the new ICRP general recommendations, of experience with implementing the 1996 BSS, and of IAEA standards and other strategic documents developed since 1996, a process to revise and update the International Basis Safety Standards was launched in 2005, with the new version expected to be approved by all co-sponsoring organisations through their own institutional mechanisms.

Additionally, the IAEA has addressed the principle of optimisation within two main publications:

- Safety Guide on *Occupational radiation protection*, RS-G-1.1 (IAEA, 1999), wherein the main features of ALARA are described, as well as the role of dose constraints and investigation levels.
- Safety Report on *Optimization of radiation protection in the control of occupational exposure*, Safety Report Series No. 21 (IAEA, 2002), which gives practical recommendations for the assessment of exposure situations, the means to reduce exposures and the definition and implementation of ALARA plan.

***European Atomic Energy Community (EURATOM)***

The EURATOM Treaty came into being on 1 January 1958 following a treaty signed in Rome in March 1957, having the same Member States as the European Economic Community (EEC). The goal of EURATOM is to promote common efforts between its members in the development of nuclear energy for peaceful purposes.

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4. FAO, IAEA, ILO, OECD/NEA, PAHO, WHO.

Article 2 (b) of the Treaty establishing the European Atomic Energy Community provides for the establishment of basic safety standards for the health protection of workers and of the general public against the dangers of ionising radiation. These standards are specified in a European Union (EU) directive developed by the European Commission and are therefore legally binding on member states. The "EURATOM Basic Safety Standards for the protection of the health of workers and the general public against the dangers arising from ionizing radiation" (EC, 1996) laid down in Directive 96/29/EURATOM adopted by the European Council in May 1996, are based on the recommendations of ICRP Publication 60. Reflecting their status as a legislative act, the EU Member States individually enact national legislation implementing the requirements of the directives.

As with the 1996 International BSS, a process was launched to update the 1996 EURATOM BSS, with the intention to develop a revision that reflects the new ICRP recommendations, new scientific data and implementation experience.

***OECD Nuclear Energy Agency***

The Nuclear Energy Agency (NEA) is a specialised agency within the Organisation for Economic Co-operation and Development (OECD), an intergovernmental organisation of industrialised countries established in 1958. Its mission is to assist its member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for the safe, environmentally friendly and economical use of nuclear energy for peaceful purposes. The NEA works as: a forum for sharing information and experience and promoting international co-operation; a centre of excellence which helps member countries to pool and maintain their technical expertise; and a vehicle for facilitating policy analyses and developing consensus based on its technical work.

The NEA is the only inter-governmental nuclear energy organisation which brings together developed countries of North America, Europe and the Asia-Pacific region in a small, non-political forum with a relatively narrow, technical focus. Generally, the topics addressed by the NEA are specific, state-of-the-art technology or policy-oriented areas, from which the international and national guidance documents can be developed. Performing the work in close collaboration with other international organisations assures that its efforts are complementary.

Within NEA, the Committee on Radiation Protection and Public Health (CRPPH) has the responsibility to study various radiological protection issues and take actions to support national authorities in the adoption and maintenance of high standards of protection in the use of ionising radiation. The NEA has worked in collaboration with the ICRP to "road-test" draft recommendations as to their implications for policy, regulation and application, and co-sponsors the International Basic Safety Standards.

***Other organisations contributing to the elaboration of radiation protection standards***

In addition to the work undertaken by the international organisations described above, other inter-governmental and non-governmental organisations and networks of practitioners also provide a source of feedback that contributes to the elaboration of new standards. These include, for example:

- The Information System on Occupational Exposure (ISOE): provides a forum for radiation protection experts from utilities and national regulatory authorities to discuss, promote and co-ordinate international co-operative undertakings for the radiological protection of workers at nuclear power plants. ISOE is jointly sponsored by the OECD/NEA and IAEA.
- The International Radiation Protection Association (IRPA): provides a medium whereby radiation protection practitioners worldwide may communicate more readily with each other and through this process advance radiation protection in many parts of the world.

- The European ALARA Network (EAN): furthers specific European research on topics dealing with optimisation of radiation protection and facilitates the dissemination of good ALARA practices within European industry, research and medical sectors.
- The Western European Nuclear Regulators Association (WENRA): serves as a network of chief nuclear safety regulators in Europe to exchange experience and discuss significant safety issues in order to facilitate development of a common approach to nuclear safety and provide an independent capability to examine nuclear safety in applicant countries to the European Union.

## 2.3 National regulatory policy

The regulation of nuclear and radiation safety is a national responsibility, for which international standards provide a harmonised basis and promote consistency. Depending on the regulatory framework, national regulations can have varying levels of influence on the application of work management.

It is the nuclear power utility's duty, in the first instance, to ensure that a particular operation is safe from the perspective of nuclear safety and radiological protection, which must be done within the applicable regulatory framework. An effective regulatory regime will provide an appropriate balance between prescriptive and performance-based rules, enabling the utility to integrate flexibility in the application of work management. To demonstrate the influence that regulations can have on approaches to work management, two categories of regulations, and the relationship between them, are considered: those that address nuclear safety, and those that address radiological protection.

### *Nuclear safety regulations*

Although all nuclear regulations are intended to protect workers, the public and the environment from the harmful effects of radiation exposure, one aspect of this protection is the safety of nuclear installations and the prevention of nuclear accidents. Regulations addressing nuclear safety issues may place specific obligations on licensees, which may impact the exposure of workers. Examples include regulations relating to system inspection and maintenance (including their extent and frequency) which may vary both from country to country as well as in their degree of flexibility.

Exposure of workers performing maintenance and inspection in compliance with nuclear safety requirements should be warranted by the benefit in increased plant reliability. Depending on the safety significance of a particular system, a regime of *performance-based* plant condition monitoring and breakdown maintenance may offer advantages over a more *prescriptive* system of preventative maintenance based on a pre-determined schedule. For example, if the annual frequency of an inspection and maintenance programme is high, the application of work management may be constrained. On the other hand, the flexibility to undertake combined inspections less frequently or to postpone inspections until more optimal radiation protection conditions are achieved, such as following system decontamination, may save dose and allow a broadly optimised inspection and maintenance schedule.

As another example, whereas a prescriptive rule could require systematic steam generator tube inspection during every refuelling outage, a performance type rule would require that future inspections be scheduled according to the outcomes of the last inspection. This later type of regulation fulfils the regulatory requirement to protect workers and the public while providing the utility with the flexibility to more broadly optimise occupational exposure. Recent trends in regulation have, in fact, been towards performance standard type rules as opposed to more prescriptive rules, and this tendency supports the principles of work management.

***Sweden and Belgium: Reduction of steam generator inspection***

In Sweden, at Ringhals plant (3 PWRs and 1 BWR), it was agreed by the Safety Authority (SKI) that, for the PWR having benefitted from a steam generator replacement, the new steam generators can be inspected every two years. All tubes have to be inspected within a 5-year period and 50% are inspected every 2 years.

In Belgium, after the steam generator replacement at Doel 3 and Doel 4, only one steam generator was opened and checked each year. However, the Belgian safety authorities accepted, after negotiation with Electrabel, that each steam generator would be inspected only once every six years. The Doel plant opted for opening two steam generators each third outage, enabling two consecutive unit outages without opening a steam generator. The inspection covers the entire length of a random sample of 40% of the tubes; 10% of the tubes are also checked in the roll transition zone.

***Japan: Reduction of outage frequency***

In Japan, prior to 2007, the plants followed a 13 month operating period. A new inspection system, announced in 2007, allows maintenance activities to be performed according to the maintenance programme of each plant. In this system, inspections have shifted from a uniform inspection to a site-oriented inspection according to the characteristics of each plant, allowing 18-24 month operating periods.

***United States: Reactor oversight process and "risk-informed" inspection***

The US Nuclear Regulatory Commission (NRC) has embarked on a programme to improve the effectiveness and efficiency of its regulatory process. A key aspect of this programme is a change in the way the NRC conducts its inspection process for nuclear power reactors. The basis of this approach is to risk-inform NRC inspection of nuclear power reactor licensees. Fundamental to this is the concept that licensee performance meeting the objectives and key attributes of the process provides reasonable assurance that public health and safety is maintained. Seven safety cornerstones were developed, including occupational radiation safety.

For example: the NRC radiation protection inspection procedures direct the inspector to focus on the licensee's controls established for work performed in the most radiological risk significant areas of the plant. These include locked high and very high radiation areas, and areas where there is a potential for dose rates to change dramatically (such as around the radwaste sluice tanks).

### *Radiation protection regulations*

In addition to nuclear safety regulations, other national regulations and guidance refer directly to radiation protection issues. These can include dose limits for workers and the public, as well as operational restrictions established by the authority for use in the monitoring of activities at existing facilities (such as action levels or investigation levels, etc.) Objectives of such regulations and guidance are to ensure that protection is optimised and that as statutory limits are approached, measures are taken to prevent them being exceeded.

Regulations addressing the principle of optimisation of protection for both workers and the public can have an additional influence on work management in relation to control of occupational exposures. In implementing this principle, there is often a balance between measures aimed at further reducing the generally very low public doses from routine operation, and those which may have the potential for achieving substantial reductions in occupational exposure. For example, the use of certain effluent reduction technology might lead to occupational doses from its installation, operation, maintenance and decommissioning that might not be proportionate to its benefit in terms of decreased public dose. It is therefore important that resulting exposures are appropriately managed and options are agreed by all relevant stakeholders. This is a qualitative and quantitative process that should be adapted to each situation so that both public and occupational exposures can be considered ALARA.

*Dose limits*

Regulatory dose limits for occupationally-exposed workers in most countries adhere to ICRP guidance (1991, 2007), the 1996 International BSS or the 1996 EURATOM BSS, although the manner of their implementation may vary.

Table 1. **Regulatory occupational dose limits (whole body) in ISOE participating countries**[5]

| Occupational dose limits (whole body) | Country |
|---|---|
| 20 mSv in one single year | Germany, Italy, the Netherlands, Pakistan,[6] Romania, Slovenia,[6] United Kingdom |
| 20 mSv/year per 12 rolling months | Belgium, France |
| 100 mSv/5 years and<br>50 mSv per any single year | Armenia, Brazil, Bulgaria, Canada, China, Czech Republic, Finland, Hungary, Japan, Korea, Lithuania, Russian Federation, Slovak Republic, South Africa, Spain, Sweden, Switzerland |
| 50 mSv/year | Mexico, United States |

With regards to the management of doses for outside or transient workers who may be employed by different utilities and/or working in several countries, employers and licensees need to be aware of the dose history of these workers in so far as the information is available. After the completion of work, those who are responsible for recording worker dose information into the individual dose records of such workers need to ensure that this is done.

***Japan: dose passports***

When an NPP needs to temporarily employ US personnel (for example qualified welders for underwater welding), they will control the exposure of such workers under the Japanese dose control system, taking their previous exposure into consideration. If the workers have their own dose passport, the Japanese utility will accept and complete this passport.

***Europe: experience and follow-up with outside workers***

Most of the EU states have personal dose record documents for outside workers. Some also have national dose record systems which may be specific for outside workers, or applicable to all radiation workers, as in France and Spain. In Spain, the official personal document includes not only personal dose information, but also other information such as training history, medical surveillance, etc.

A 2006 European workshop on outside workers concluded that most countries desire a more standardised outside worker personal dose record document (EAN, 2006). This does not however imply the need for a document that would be strictly identical in terms of content in each member state. Concerning standardised content, a degree of flexibility was considered desirable, with the European Commission setting a minimum required level of information. The question of language was considered to be crucially important: such a document would at least need to be written in English and the national language of the state where it was issued.

***ALARA regulation and guidance***

National regulatory authorities may introduce additional regulations or guidance addressing ALARA planning. Such regulation or guidance can focus on the procedures or processes that may be

5. As of time of publication of this report.
6. In special circumstances under very specific conditions, an effective dose limit of 50 mSv/year may be authorised by the regulatory authority. The total dose over 5 years should not exceed 100 mSv.

adopted by licensees to implement systematic and efficient ALARA programmes. In addition, regulatory authorities can also play an important role in reviewing licensees' ALARA programmes. In some cases, regulatory authorities might set a collective dose threshold above which formal or official ALARA planning procedures must be approved by the authority. Moreover, a regulatory body can require involvement of external experts to provide opinion and advice in case of high exposure jobs.

***Canada, United States: ALARA basis***

In Canada, the Radiation Protection Regulations [RPR 4(a)] include an ALARA requirement for all licensees to establish a radiation protection programme to keep exposures ALARA through the implementation of a number of control programmes, including:

- Management control over work practices.
- Personnel qualification and training.
- Control of occupational and public exposure to radiation.
- Planning for unusual situations.
- Verifying the quantity and concentration of any nuclear substance released as a result of the licensed activity.

The regulatory body (CNSC) issued a guide on ALARA (G-129, revision 1, October 2004) which guides licensees on the type of action that aims to effectively control and minimise doses. It outlines the importance of an explicit commitment by senior management to limit doses to magnitudes that are ALARA, the need for suitable programmes to achieve this objective, and the value of reviewing work-related doses periodically to ensure that they continue to be adequately controlled. The CNSC, among other things, looks at the process adopted by licensees to maintain doses ALARA as evidence of compliance with paragraph 4(a) of the Radiation Protection Regulations.

In the United States, NRC regulation 10 CFR 20.1101, Radiation Protection Programmes, provides the regulatory requirements for ALARA:

- Each licensee shall develop, document, and implement a radiation protection programme commensurate with the scope and extent of licensed activities and sufficient to ensure compliance with the provisions of this part.
- The licensee shall use, to the extent practical, procedures and engineering controls based upon sound radiation protection principles to achieve occupational doses and doses to members of the public that are as low as is reasonably achievable (ALARA).
- The licensee shall periodically (at least annually) review the radiation protection programme content and implementation.

***France, Germany, Korea, Slovenia: ALARA regulation***

In France, the decree related to occupational radiation protection (*Décret n° 2003-296 du 31 mars 2003 relatif à la protection des travailleurs contre les dangers des rayonnements ionisants*) specifies that, in order to apply the optimisation principle, for each operation taking place in a controlled area, a provisional estimate of occupational collective and individual doses shall be made, and collective and individual dose objectives for the operation shall be set at the lowest level possible according to the available techniques and the nature of the operation to be undertaken.

In Germany, regulation states that anyone intending to engage or engaged in activities causing radiation is obliged to keep all types of radiation exposure or contamination of persons or the environment as low as practicable, taking due account of the state-of-the-art and in consideration of the circumstances of each individual case, even where the values are below the limits. The regulations do not contain any mandatory criteria for implementing overall optimisation based on monetary aspects. This allows interpretation both along the lines of minimisation as well as optimisation. Official practice still aims to achieve "minimisation", however, the VGB has made recommendations for the use of cost-benefit analysis in the choice of radiation protection options.

***France, Germany, Korea, Slovenia: ALARA regulation*** (Cont'd)

In Korea, the utility KHNP has always strived to reduce occupational exposures to levels that are ALARA and has made remarkable strides over the last two decades. These reductions have been achieved through a variety of means at a number of levels, even if the main driver has been compliance with regulatory requirements. ALARA requirements were incorporated in Korean regulation as follows:

- 1958: Establishment of the Atomic Act.
- 1983: General Revision based on ICRP-9 (MPD, MPAD, MPC).
- 1994: Inclusion of the ALARA principle.
- 1998: Transition to dose limit of 100 mSv/5 years and 50 mSv/year maximum (200 mSv/5 years until 2002).
- 1999: Requirement to implement the ALARA programmes.
- 2001: Application of the concepts of ALI, DAC.

In Slovenia, the nuclear and safety regulations have introduced the optimisation plan as a part of the requirements for radiation exposure assessment (Official Gazette No. 115/2003 – SV5) related to the rules for authorisation of radiation protection practices (Official Gazette No. 13/2004 – SV8, and No. 27/2006 – JV2/SV2).

***Japan, Spain: Regulatory review***

In Japan, the authority reviews and approves the Operational Safety Programmes which licensees are required to submit and which serve as the basis for keeping occupational exposures ALARA.

In Spain, in the 1990s, the regulatory body (CSN) issued a guide on optimisation of radiation protection in NPPs (GSG-01.12 "Aplicación práctica de la optimización de la protección radiológica en la explotación de las centrales nucleares" – Practical application of the optimisation of RP in NPP operation). This includes general criteria for the ALARA framework such as establishment of responsibilities, necessity of official documentation and guidelines for ALARA programmes (indicators, objectives, training, management, etc.) These criteria are implemented in different official documents at different organisation levels and are revised and assessed periodically.

## 2.4 Industry internal procedures: operational restrictions

As part of an utility's internal procedures, operational restrictions may be established to encourage reduction of individual occupational doses or to facilitate the identification of workers who might reach the regulatory dose limits. Such restrictions may also include dose constraints, dose targets or dose objectives. It must be noted that, according to national frameworks, different terminologies are used by the operators for these operational restrictions. "Dose constraints" or "dose targets" are usually used to specify a maximum annual individual dose to be received that is lower than the dose limit. The levels of individual dose giving rise to a specific action (control, access restriction, etc.) are called "investigation levels" or "warning levels". Finally, in some cases, maximum job-related levels in terms of individual or collective exposure may also be set. Such levels are called "dose objectives" or also "dose constraints". They are set at the preparation phase of a job to estimate what would be the maximum dose for this job and to perform optimisation of protection below this level. They can also be used after job completion to compare actual doses with the objectives.

While these may be referred to by different names, they are operational values used by utilities in day-to-day dose management. They may also be used when considering radiological protection criteria in the design of a new process or facility. In a work management sense, these restrictions provide utilities with tools to facilitate individual dose management within the regulatory limits.

***Canada: Radiation protection regulations and establishment of action levels***

In Canada, the General Nuclear Safety and Control Regulations require a licence application to include "any proposed action level for the purpose of section 6 of the Radiation Protection Regulations" (RPR). RPR 6(1) defines an "action level" as a specific dose of radiation or other parameter that, if reached, may indicate a loss of control of part of a licensee's radiation protection programme and triggers a requirement for specific action to be taken. RPR 6(2) stipulates that "When a licensee becomes aware that an action level referred to in the licence for the purpose of this subsection has been reached, the licensee shall:

- Conduct an investigation to establish the cause for reaching the action level.
- Identify and take action to restore the effectiveness of the radiation protection programme implemented in accordance with section 4.
- Notify the Commission within the period specified in the licence."

Action Levels are an important tool in alerting the licensee and the CNSC to any potential losses of control.

In addition, some Canadian utilities establish Exposure Control Levels (ECLs) and Administrative Dose Limits (ADLs) within their radiation protection programme to ensure an appropriate level of management control is applied as a worker approaches dose limits to minimise risk of exceeding regulatory limits.

An Action Level (that forms part of the license) requires reporting to the CNSC. Administrative control levels, operational intervention levels, etc. are essentially internal tools for dose monitoring and control, and often do not require individual reporting to the CNSC. Both are early warning indicators of potential problems in radiation protection and both require follow-up actions.

***France: Operational dose restrictions***

In order to respect the annual dose limits, the French utility EDF has implemented two warning dose levels for regularly exposed workers: i) a pre-warning level of 16 mSv/year on 12 rolling months, and ii) a warning level of 18 mSv/year. If a worker reaches the pre-warning level, a special surveillance is performed, and his working environment is adapted, possibly in co-operation with the medical services. However, the worker is still allowed to enter the controlled area. If the warning level is reached, the worker has to stop his activities within the controlled area until the following actions are made: the employer, the health physicists and the medical services are informed; a special risk analysis is conducted in order to estimate the worker's future doses; and the employer gives a specific authorisation to continue the work.

***Germany: Work to be done outside outage period (Philippsburg NPP)***

If a system failure must be eliminated prior to an outage, due to plant safety or technical requirements, the team planning radiation protection activities asks to reduce the power of the plant and estimates the planned individual dose on the basis of the area dose rate. The main rule is that, in this case, the individual dose should not exceed 1 mSv.

***Japan: Dose targets***

In Japanese regulation, occupational dose limits are set at 100 mSv/5 years and 50 mSv/year; these are not exceeded in the country's nuclear power plants. However, the utilities are making an effort to reduce occupational exposure by setting a lower target of individual dose, for instance 20 mSv/year, in their radiation protection management. In Japan, 66 000 persons work in nuclear power plants, of which only 0-3 persons exceeded 20 mSv in one year between FY2002 and FY2007.

***Romania: Dose control points for optimisation of internal exposure (Cernavoda NPP)***

The Dose Control Point (DCP) is an internal administrative limit for the control and limitation of occupational radiation exposure. It represents half of the effective dose available at any time until the administrative limit of 18 mSv/year is reached. At the beginning of a dosimetric year, the DCP is set at 9 mSv, and decreases with increasing received dose. The DCP cannot be exceeded in any single exposure (single task/job for a single entrance in the radiation field) without approval of the Station Health Physicist.

***Romania: Dose control points for optimisation of internal exposure (Cernavoda NPP)*** (Cont'd)

For CANDU reactors the major contributor to the internal dose is tritiated heavy water (DTO). Besides the administrative total effective dose limit of 18 mSv/year, other administrative controls are implemented in order to optimise protection for internal doses due to the intake of DTO:

- Removal limit of 1 mSv committed dose: when DTO concentration in urine exceeds 1.2 MBq/L, daily sample submission is required and the subject is not allowed to enter a radiological zone with tritium in air contamination until the concentration decreases.
- Investigation level of 0.3 mSv for follow-up of internal exposure to tritium: investigations are made by the departments' ALARA co-ordinators.
- Threshold of 0.03 mSv anticipated committed dose for the use of respiratory protection equipment, even when the tritium dose rate does not exceed the mandatory respiratory protection level of 0.05 mSv/h.
- Monthly targets for collective dose for station and work groups.
- Performance indicators to improve station/work group performance.

***Slovenia: Dose constraint and operational dose limit (Krško NPP)***

At Krško NPP, the plant operational limit for individual whole body dose due to external radiation is 10 mSv in a year. Approval by the radiation protection superintendent and technical director is required in order to exceed this limit. The operational limit has been slightly exceeded only for a few exposed individuals in jobs related to welding or radioactive waste processing.

In accordance with Slovenian regulation, the plant has proposed to the authority external and internal dose constraints. These values are used as authorised dose constraints:

- The dose constraint due to external radiation is 15 mSv in a year for category A workers and 6 mSv for category B workers.
- The dose constraint due to internal exposure is 0.2 mSv in a year.

If these dose constraints are exceeded, the Slovenian Radiation Protection Authority must be informed and corrective actions taken by the plant.

## 2.5 Summary

Radiation protection principles and standards are developed at the international level, providing a sound basis for the development of national regulations. These regulations usually deal with i) safety and ii) radiation protection. In the field of safety, there is an effort to develop and implement "performance based" plant maintenance rather than prescriptive pre-scheduled maintenance. This typically allows reductions in maintenance volume and therefore occupational exposure. In the field of radiation protection, specific rules can be introduced to foster the optimisation of radiation protection. In addition to the regulatory framework, utilities can develop their own radiation protection internal rules, integrating operational restrictions for the management of individual and collective doses.

# 3. ALARA MANAGEMENT POLICY

*ALARA – As Low As Reasonably Achievable – is usually considered as a way of thinking, a philosophy, continuously questioning whether all reasonable action has been done to reduce exposures. To foster the practical implementation of this philosophy, it is necessary to create specific organisations, distribute individual and collective responsibilities regarding ALARA and establish common rules to be applied.*

## 3.1 Introduction

The ALARA approach consists in always questioning whether the best has been done in the prevailing circumstances, and whether all that is reasonable has been done to reduce doses (ICRP, 2007). As with the implementation of any initiative, success depends upon motivation and support originating at the highest levels of the organisation. Plant management must put in place a management structure or organisation to ensure that radiation protection is appropriately considered in all jobs performed. In particular, plant management must be willing to support, in policy and budget, a multi-disciplinary team approach to plan, schedule, implement, and follow-up jobs. Although such structures vary from country to country and from utility to utility, many of the key points of these organisations are common, as discussed in this chapter.

## 3.2 Plant ALARA programmes

While every utility should respect the "spirit of ALARA", a structured ALARA programme should be developed and implemented at all nuclear power plants. Such programmes express the commitment of management to appropriately implement radiation protection measures, define the objectives and describe the specific structures, procedures and tools necessary for their implementation. These generally include:

- The setting of programme goals and objectives, for example, requirement for establishment of collective dose objectives for the year, for outages, and for specific jobs.
- A definition of resources available to meet the programme objectives.
- The assignment of roles and responsibilities.
- A description of the role and functioning of an "ALARA Committee".
- The specification of radiation protection structures (outage co-ordination, specific radiation protection work groups, etc).
- The elaboration of an education/training policy.
- Working methods and requirements for job preparation, implementation and post-job analysis.
- The means to measure the success of ALARA efforts, for example, a monitoring system which provides timely, periodic feedback up and down the management chain as to the status of achieving programme goals and objectives.
- The measures necessary to effect corrective action when feedback information indicates programme shortcomings or failures.

***Russian Federation: Standard ALARA programme for all Russian NPPs***

In 2000, the utility Concern Rosenergoatom initiated ALARA programme implementation at all Russian NPPs. The Standard ALARA programme for Russian NPPs was elaborated by the All-Russian Research Institute for NPP Operation (VNIIAES) in 2000. The main features of the programme are:

a) ALARA organisational structure at NPPs:
   - ALARA Committee.
   - ALARA Groups: Main tasks and functions include job analysis, work preparation performance and feedback, etc.

b) Standard programme of activities aimed at occupational exposure reduction, including:
   - Organisational activities.
   - Source term reduction activities.
   - Time saving activities.

In accordance with the Standard ALARA Programme, each NPP has elaborated a local ALARA programme. For example, the local programme at Kalinin NPP includes the following additional features:

- Dose goals regarding the ALARA programme.
- ALARA organisational structure.
- Sharing of responsibilities concerning the implementation of the ALARA programme.
- Measures for reducing occupational exposures during maintenance and normal operation.
- Procedures for occupational dose planning, analysis and recording.
- Special equipment for dose reduction.
- Employee education on ALARA Programme.
- List of jobs of 1 man·Sv or higher which should be optimised for exposure reduction.

### 3.3 Roles and responsibilities for the implementation of ALARA

All workers and managers must share the responsibility for the implementation of the ALARA programme in their field of activity.

Management commitment to any project is always demonstrated by management presence and support. Management policy should thus encourage managers to make frequent visits to the work site(s), and to have first-hand knowledge of project status and problems. Plant tours should be conducted with a specific purpose or area of concentration (e.g., housekeeping, cleanliness, worker procedural compliance, tool staging adequacy, specific repair task progress, etc.) This can be facilitated by the appropriate delegation of authority, which will free managers' time to accomplish thorough plant observation tours.

In addition, management policy can require that work be performed within specified limits (dose, man-hours, time, etc.) This can be implemented via contractual requirements for contractors, and by management's willingness to fund, in terms of money and personnel, the projects necessary to meet the assigned goals. The communication of these goals to all workers, and of management's commitment to these goals, is also very important.

Ownership of ALARA philosophy is a responsibility of all plant functional areas, which generally include:

- Plant managers: responsible for ALARA performance, including setting internal standards.
- Chemistry: chemistry specifications, key role in developing shutdown procedures, etc.
- Operations: implementation of chemistry advice to maintain plant within chemistry specifications, maintain water levels in accordance with RP advice etc.
- Maintenance: foreign materials exclusion, preparation of tools and work areas, mock-up training, etc.

- Radiation protection: advise managers and other work groups, set standards, pragmatic implementation of rules and regulations, etc.
- Engineering support: using operating experience to minimise maintenance requirements, etc.
- Work planning and scheduling: understand how work schedules are linked to plant configuration and how deviations from plans can affect ALARA etc.
- Outage logistics: account for logistics during outage periods (as distinct from normal operations).
- Facilities management: e.g. housekeeping and cleanliness.
- Contractors.

It should be noted that the organisation and structure of these functions may differ from utility to utility, and possibly between normal operations and outage periods. It is thus difficult to elaborate what could be the "best" distribution of responsibilities. However, some generic rules can be drawn from the past-experience of numerous operators, which are discussed further in the following sections.

***United Kingdom: Role of management***

In the United Kingdom, the employer is required by law to appoint suitable persons, in sufficient number, to act as radiation protection supervisors. These people are responsible to the employer for ensuring that the workers follow properly the plant radiological safety rules. To be effective, these supervisors must command the authority of a supervisor and be knowledgeable about the work being performed and how the radiological protection requirements are effective at keeping doses ALARP (as low as reasonably practicable). At Sizewell B, each front-line supervisor (in maintenance, operations, etc.) is appointed as a "radiation protection supervisor" and is involved in briefing their team on Radiological Work Permits and ensuring that rules are followed. In addition, all users of ionising radiation have been reminded by the regulatory authority that the managers must be actively involved in promoting ALARP and in decision making that affects occupational exposure.

***Distribution of ALARA responsibilities***

While the distribution of responsibilities may vary between countries and utilities, the following broad areas of responsibilities are generally applicable.

For large utilities, the following centralised functions for ALARA at the corporate level usually include:

- Elaboration of the overall ALARA philosophy.
- Fleet-wide standardisation of ALARA policy and procedures.
- Elaboration of generic action plans for dose reduction and optimisation.
- Establishment of short (3 months to 1 y), medium (1-5 y) and long-term (e.g., 10 y) dose targets, corporate wide or for each site if applicable.
- Independent challenge boards for detailed review of major component replacement (e.g., steam generator or reactor vessel head replacement).
- Fleet-wide sharing of ALARA expertise and experience.
- Establishment of dose targets for new build.

In addition, for all utilities, the following organisational roles and responsibilities for ALARA are usually assigned, although it is recognised that different variations of this exist in practice:

*Senior management* must promote, resource and support the ALARA programme to ensure its overall success.

*Plant managers* are responsible for the overall ALARA programme in accordance with the policy and objectives of the utility (which in some cases may be elaborated at the corporate level). To this end, they:

- Participate in the formulation of the station ALARA programme goals and objectives.
- Support plant personnel in terms of the implementation of radiation protection measures, particularly the radiation protection manager.
- Ensure that open channels of communication exist to the corporate level.
- Review the status of the plant's efforts to reduce exposure.

*Department managers* are responsible of the implementation of the station ALARA programme in their field of activity and for assuring that work is performed in accordance with ALARA procedures. To this end, they:

- Define the contribution of their department to the station ALARA programme.
- Establish the dosimetric goals of their department.
- Validate and control the procedures and methods elaborated to reach the objectives.
- Support their personnel in the implementation of the ALARA principle.
- Review periodically the performances of the department with respect to the ALARA programme objectives.

*Radiation protection managers* are responsible for the development and implementation of the radiation protection programme, and must have the authority to "go up the management chain" to resolve radiation protection issues and concerns. In particular, they:

- Develop methods and procedures for implementation of the ALARA principle.
- Identify and analyse conditions and operations (including risk) that can cause significant exposure.
- Implement an exposure control programme and provide feedback data to other departments (radiological data, exposure levels, etc.).
- Implement initial radiation protection training and continued input to plant's training programme.

*Radiation protection technicians* are responsible for following operations in the field to help assure that radiation protection policies are carried out and that jobs are implemented in accordance with the ALARA principle. Their responsibilities include:

- Providing assistance and advice to workers to motivate them to adopt an ALARA behaviour.
- Following jobs to ensure the respect of safety and radiation protection procedures.
- In some plants, stopping work in case of serious deviation from dosimetric objectives, or when there is a significantly increasing radiological risk for workers.

Finally, each *individual worker* is responsible for maintaining his or her exposure ALARA by following radiation protection training and procedures and by identifying dose reduction opportunities to management. In particular, workers are responsible for:

- Maintaining their level of individual exposure and that of the workers around them as low as reasonably achievable by applying good radiation protection procedures and practices.
- Identifying and suggesting improvements and good practices for the reduction of exposure.

***Division of ALARA responsibilities between utilities and contractors***

There is a need for a clear division of responsibilities between utilities and contractors regarding the implementation of ALARA. Utilities, as owners of the source, are usually responsible for the work environment. If the contractor is using the utility's working procedures, the utility is responsible for optimising the radiation protection at the working level. If, on the other hand, the contractor is elaborating its own procedures, then it is responsible for demonstrating to the utility that protection has been optimised. In some cases, it is possible to introduce specific contractual requirements addressing radiation protection performance. However, in all cases, the dialogue between the utility and the contractor is a key element for improving radiation protection.

***France: Contractors at EDF***

For national maintenance operations performed by national contractors, EDF has introduced specific obligations within multi-year contracts related to radiation protection compliance. These contracts include a part detailing a fixed amount of work, and an "optional" part detailing possible additional work. If a contractor does not fulfil the obligations specified in the contract, or does not demonstrate good behaviour regarding radiation protection, the optional part of the contract might not be awarded to the contractor.

***Slovenia: Contractor responsibilities (Krško NPP)***

Considering the contractor's responsibility for ALARA, an efficient management policy is to introduce the obligation for ALARA into commercial contracts. At the Krško plant, the contractor can be liable in the case of high collective dose activity for payment of a penalty to the plant as a result of non-compliance with ALARA requirements. If the overall dose exceeds the ALARA Plan by 10 man·mSv, the contractor must pay an amount of €10 000, plus an additional amount of €5 000 for each additional 5 man·mSv over the dose compared to the ALARA Plan. Settlement of the penalty is agreed upon by both parties during the exit meeting. In this case, the alpha value set by the plant is also used for commercial reasons to force the contractor to take an appropriate responsibility for ALARA.

## 3.4 The ALARA Committee and other specific ALARA organisations

According to a utility's organisation, ALARA Committees might be established at various levels: corporate level, engineering level, plant level, etc. For utilities managing a large number of plants, it might be useful to create an ALARA Committee at the corporate level in order to disseminate the main objectives of the utility's ALARA policies and coordinate radiation protection actions amongst the plants. Such a committee is generally chaired by a representative from the RP top management and members are representatives from the plant top management. Some utilities that have established engineering departments at the corporate level might also set up ALARA Committees for co-ordinating the integration of radiation protection aspects into engineering developments (*e.g.* elaboration of plant modifications or special maintenance jobs, etc.)

### *Plant ALARA Committee*

A Plant ALARA Committee is established in some utilities to provide an ongoing multi-disciplinary planning and review of the ALARA programme. Such a committee is generally chaired by a representative from plant top management to ensure a capacity for decision making, and members are generally representatives from the various plant departments, including radiation protection, chemistry, maintenance, operations, engineering, planning, scheduling and logistics.

The committee is typically responsible for approving and reviewing the ALARA programme proposed by the plant manager, of setting annual occupational exposure goals and of assuring that the programme is implemented and robust. The ALARA Committee should meet periodically to review station ALARA performance, evaluate individual dose reduction suggestions and make recommendations to management regarding the effectiveness of the ALARA programme. The minutes of each meeting should specify who is responsible for each action decided by the Committee, and should be distributed to all departments.

The Plant ALARA Committee can be consulted in order to validate the ALARA plans of some maintenance jobs. The decision to present such jobs to the committee usually depends on the level of expected individual or collective exposures associated with the job, or when an arbitration has to be done in selecting the best protection option (see also Section 3.5).

### *ALARA engineering group*

In order to facilitate the practical implementation of the ALARA programme, it can be useful to create a specific ALARA engineering group composed of radiation protection professionals and engineers. The role of this group can include participation in job planning, scheduling and preparation meetings, detailed review of work procedures, design of temporary shielding, etc.

***Korea: ALARA organisation and responsibility (KHNP)***

KHNP revised its ALARA programme and developed a standard ALARA procedure to meet ICRP-60 recommendations implemented by Law (1998). Previous ALARA procedures had been applied to each plant until the standard procedure was developed for all plants in 2000. The organisation and responsibilities of the ALARA Committee and ALARA Practical Committee, shown below, are described in the standard procedure.

| Position | ALARA Committee | ALARA Practical Committee |
|---|---|---|
| Chairman | Plant manager | Radiation safety manager |
| Secretary | Radiation safety section manager | Radiation protection section chief |
| Members | Vice-plant manager<br>QA manager<br>All-plant manager<br>Subcontractor manager | Workgroup section chief<br>Subcontractor workgroup manager<br>Radiation service subcontractor manager<br>Member recommended by the Chairman |

The ALARA Committee is responsible for general ALARA programme reviews (RP policy, annual target, long-term ALARA strategy, etc.) Both committees are responsible for the following items, depending on the expected job doses:

- Review of radiation protection optimisation planning; Post-work ALARA review if actual dose exceeds the expected dose by 25%.
- Review of the radiation safety control plan.
- Review of the optimisation plan for radiation protection (whenever requested by a chairman).

***Germany: The creation of the ALARA Committee as a result of an OSART (Phillipsburg NPP)***

An OSART review conducted in 2004 suggested the establishment of an ALARA committee. This committee holds a meeting two times a year for outage preparations, and for look back previews of annual events. The ALARA committee consists of members of plant management, plant operator and the responsible RP commissioners of the particular departments i.e. maintenance and operations. The committee was successfully established and is an important contact to the plant management. Thus more important radiation protection preparation can be introduced and elaborated. This means that the most recent projects and those with potential flaws will be openly discussed and analysed. The committee encourages a willingness to address radiation protection issues.

***Romania: ALARA culture (Cernavoda NPP)***

At Cernavoda NPP, the ALARA culture consists of the following:

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

***Romania: ALARA culture (Cernavoda NPP)*** (Cont'd)

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

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

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

***United States: The ALARA engineering group***

In the United States, the ALARA engineering group is generally composed of several health physicists and technicians who conduct routine ALARA reviews and who perform dose accounting functions. Typically, the group performs 200-300 ALARA job reviews annually, recommends annual and outage man·Sv goals to the ALARA Committee, administers the exposure tracking data base, remote monitoring systems, telemetry electronic dosimetry and robotics. Permanent and temporary shielding designs are also the responsibility of this group. This group should work closely with all phases of job planning, scheduling and preparation to assure that appropriate radiation protection measures are included, for example maintaining water levels in piping to achieve shielding benefits.

## 3.5 ALARA reviews

ALARA reviews are usually performed by the ALARA engineering group if such a structure has been created. However, whatever the organisation, these should be performed by multi-disciplinary teams composed of radiation protection staff and technical specialists relevant to the particular job under review.

In applying the ALARA principle to particular jobs, it is evident that not all jobs require the same level of review. Depending upon the radiological risk associated with the job, the level of effort put into reviewing the job for the purpose of dose reduction will vary. Normally, dosimetric criteria are established which define the level of effort and which also specify the hierarchical level of approval necessary before the job can be implemented. These criteria are often set such that if the predicted level of individual dose and/or the predicted total collective dose for the job pass a certain point, then a defined level of review and approval is required.

In the selection of exposure reduction measures, decision aiding techniques like cost-benefit analysis are often effective. The use of these analyses implies the adoption of a reference monetary value for the unit of collective dose (so-called "alpha value"). In most cases, the formal use of the alpha value is restricted to decisions regarded as particularly important, whether in terms of budget or of impact on operations or installation safety. This value should be used as a "decision-aiding tool" rather than as a "decision-making tool", helping to reduce subjectivity in the decision-making process.

In most cases, it is no more than one criteria among others. However, even if the result of a decision-aiding technique is only one criteria in the decision-making process, such techniques permit users to better structure the problem, identify the decision criteria and quantify the various elements needed (collective dose, distribution of individual doses, effectiveness of radiation protection techniques, etc.) It also facilitates transparency in the decision-making process.

***Belgium, France: Classification of jobs by expected dose***

In Belgium, at Doel NPP, an ALARA file has to be prepared whose detail depends on the collective dose and on the dose rate:

- Ambient dose rate < 0.1 mSv/h (and contact dose rate < 0.5 mSv/h) and/or collective dose < 0.5 person·mSv: no detailed preparation file.
- Ambient dose rate > 0.1 mSv/h (or contact dose rate > 0.5 mSv/h) and/or collective dose of 0.5-5 man·mSv: preparation of an ALARA file with detailed planned doses and a check-list with the RP actions to be implemented.
- Collective dose of 5-25 man·mSv: a mandatory meeting between the professional and the RP staff to prepare the ALARA file together, which has to be validated by the RP staff.
- Collective dose > 25 man·mSv: the same procedure as above plus a meeting of the ALARA Committee to identify actions to reduce the collective dose.

In France, EDF has established internal rules for radiation protection including a specific chapter on optimisation of radiation protection. Depending on the collective dose, the dose rate or the contamination level, a more or less detailed ALARA analysis has to be prepared. The reference values of the collective dose and dose rate used to determine a level are the same for all EDF plants. The contamination levels are set up by each plant:

- Level 0: Ambient dose rate < 0.1 mSv/h and/or collective dose < 1 man·mSv: no specific optimisation study is required; the application of the standard rules is considered sufficient.
- Level 1: Ambient dose rate of 0.1-2 mSv/h and/or collective dose of 1-10 man·mSv: A "simplified" ALARA analysis is performed by the job planner;
- Level 2: Ambient dose rate of 2-40 mSv/h and/or collective dose of 10-20 man·mSv: An in-depth ALARA analysis is performed by the job planner in collaboration with the health physics department;
- Level 3: Ambient dose rate > 40 mSv/h and/or collective dose > 20 man·mSv: An in-depth ALARA analysis is performed under the responsibility of the health physics department, in collaboration with the job planner. This analysis should include the comparison of several protection options. It has to be accepted by the plant ALARA Committee.

***Korea: Monetary value model***

At the 2007 ISOE Asian ALARA Symposium, the Korean Institute of Nuclear Safety (KINS) proposed a new monetary value model. They surveyed alpha values used by the world NPPs and models of France (CEPN), the United Kingdom and Japan. They compared these models with the KINS model and developed a new model that considers social and economic factors such as gross domestic product and life expectancy.

***Romania: Prior assessment of radiation activity (Cernavoda NPP)***

At Cernavoda NPP, all activities involving radiation exposure are assessed from the radiation protection point of view according to station procedures. An estimated collective dose is calculated based on detailed information about activities to be performed. If the estimated total dose exceeds a predefined limit, further assessments are performed by the NPP ALARA committees in order to establish compensatory measures to minimise collective doses and radiological impact. If the estimated total dose exceeds 10 man·mSv, a safety work plan is approved to establish all the compensatory measures needed, such as hotspot shielding, pre-job mock-up or restricted use of respiratory protective equipment to minimise external dose, thus reducing individual and collective doses.

***Romania: Prior assessment of radiation activity (Cernavoda NPP)*** (Cont'd)

For each planned outage, activities are assessed and dose estimates are calculated based on previous maintenance experience. If no previous experience exists, a pre-job assessment is done based on the measured radiation fields and necessary protective measures are established. Each activity with estimated collective dose higher than 0.1 man·mSv is given a radiation work permit number and is closely monitored during performance to ensure that the established protective measures are observed and collective doses follow the predicted trend. If not, corrective measures are taken in a timely manner whenever necessary.

## 3.6 Industry ALARA guidance

In support of plant ALARA activities, some utilities have developed their own internal radiation protection guidance, including recommendations for the practical implementation of ALARA. In addition, some industry groups, such as the Institute of Nuclear Power Operations (INPO) and the Nuclear Energy Institute (NEI) have developed similar guidance based on the experience of their members.

***France : EDF internal requirements***

In France, EDF has elaborated a "Radiation Protection System of Reference" with 8 chapters presenting the regulatory requirements as well as the internal EDF requirements in terms of radiation protection. One chapter is specifically dedicated to the optimisation of radiation protection and the way to evaluate predictive doses, track doses during operations and analyse feedback experience. Another chapter dedicated to the radiation protection management gives requirements for the plant organisation (creation of ALARA committees, nomination of a manager in the Direction staff in charge of radiation protection, etc.) Additional guidance exists to help implement these requirements.

***Japan: ALARA operational safety programme philosophy***

Japanese utilities describe the spirit of ALARA in their Operational Safety Programme. In accordance with this, utilities make efforts to lower exposure using their own internal targets, for example 20 mSv/year (in comparison with the regulatory limit of 50 mSv/year).

***United States: INPO guidelines***

In the United States, INPO, created by the nuclear industry in 1979 following the Three Mile Island accident, is responsible for nuclear utility performance and assessment. All US organisations that operate commercial nuclear power plants are INPO members. INPOs mission is "to promote the highest levels of safety and reliability – to promote excellence – in the operation of nuclear electric generating plants". In that perspective, INPO issues "Guidelines for Radiological Protection at Nuclear Power Stations" to help utilities implement and maintain high standards in radiological protection and to meet collective dose objectives. INPO is also responsible for developing performance indicators.

With respect to radiation protection, a single indicator is used: the collective dose objective per unit. Every five years, INPO requests that each nuclear power plant determines what they plan to achieve (annual objective and 5-year objective). INPO then averages the "forecasts" and sets up 5-year dose goals for BWRs and PWRs. The industry's chief nuclear officers set the goals so that the nuclear stations themselves have ownership of the goals. The goal is tracked on an annual basis to measure progress of the fleet on meeting the goal. It is noted that when plants are ranking by INPO according to their annual collective dose, those below the dose goal are penalised on the performance indicator index. The performance indicator index is a composite of ten indicators and is used to measure overall plant performance. Through this practice, INPO looks for a continuous improvement of plants performance.

### 3.7 Summary

In order to spread the ALARA "way of thinking" amongst all levels of the management chain, from the company President to the worker on the floor, it is necessary to set up and structure dedicated ALARA programmes that make explicit the goals and objectives of the utility regarding optimisation of radiation protection. The responsibilities associated with the implementation of the ALARA programme should be clearly distributed among the various management levels and work specialisations. The creation of ALARA Committees or other types of specific ALARA organisations are a key element, forming "meeting points" between the main actors in ALARA implementation. This favours their involvement in the ALARA programme as well as the common elaboration of ALARA plans.

# 4. WORKER INVOLVEMENT AND PERFORMANCE

*ALARA cannot be achieved without worker involvement. It is the worker that is exposed, and it greatly depends on the worker himself to reduce the exposure. Motivation and performance can be improved by facilitating the involvement of the worker in each stage of the work, from the planning to the post-job review. In order to realise this, top management must also be committed to this process and favour a structure that encourages and takes into consideration the feedback of workers.*

## 4.1 Introduction

A topic which influences many of the stages of a job is the involvement and performance of the worker. There are many features that contribute to worker performance and which can be supported or improved by worker involvement. By engaging the worker in the task undertaken, 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 and higher job quality. Recognising that there is a hierarchy of personnel, ranging from top management and department-level (senior) management to section heads, foremen and workers, many of the aspects in this chapter will be valid for personnel of all levels.

## 4.2 Worker performance contributing to ALARA implementation

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 is improved through the application of good work management practices. To harness the knowledge and experience of the workforce in this effort, it is essential to actively engage the workforce in decision-making processes. Good workers contribute to dose reduction by performing their jobs with high quality, low dose and within schedule and budget. Structures also need to be in place to permit and encourage worker feedback. Recognising some of the more important features defining good performance, workers should:

- Be well educated and trained in the technical aspects of the job.
- Know and apply good radiation protection practices in the work place, including the practical application of the ALARA principle.
- Act in accordance with their job assignments and work in co-operation with their team.
- Assess the work to be performed and seek to improve performance within procedural requirements using their own experience – during job preparation, job implementation and post-job reviews.
- Draw on their experience to propose new tool designs or modifications to existing tools, facilities, or components as relevant.
- Recognise potential problems and be able to react to the occurrence of unexpected problems in a safe and efficient manner.
- Take advantage of information exchange networks (internal and external) to ensure that their knowledge, experience and lessons learned can be shared with and used by other workers.

One of the essential building blocks necessary to encourage good performance is personal motivation. As such, the motivation of personnel is a key element in worker involvement.

### 4.3 Education and training to implement the ALARA approach

Education, in the case of worker involvement in ALARA, deals with the concepts and good practices in radiation protection and informs personnel of their responsibility to maintain exposures ALARA. This education must be adapted to the type of personnel concerned and to their level of responsibilities. For example, a training course for managers can present an overview of the importance of, and the justification for, implementing a plant ALARA programme, its basic principles and the procedures for assessing its efficiency. Conversely, training for workers should be comprehensive and focus on the basic ALARA principles and practices, the distribution of roles and responsibilities, the various radiological protection tools (plant controlling documents, pre- and post-job review, dose reduction techniques, etc.) and guidance on conduct in case of unexpected events.

Even if not directly working in exposed areas, it is important for all workers to be aware of the radiation protection aspects and impacts specific to their areas of responsibility. For example, it is necessary for maintenance personnel to understand the possible impact of working conditions on the duration of exposure, and therefore to take them into account when defining new working procedures or developing tools which will be used in restricted areas or while wearing protective suits.

ALARA education and training should be repeated periodically, for example as a refresher course before an outage in order to inform or remind workers of the important aspects of radiation protection and of conduct in work. As part of training, special consideration should be given to:

- New personnel not yet sufficiently familiar with the ALARA approach.
- Inclusion of previous experiences from recent education and training sessions, especially from reviews and recommendations from participants.
- Providing information of relevance to the work to be performed.

***STAR self-assessment process***

Implementation of ALARA during work performance may also benefit from education and training on the use of the STAR self-assessment method to reduce mistakes, incidents and accidents and prevent both unnecessary doses and personal injuries. This technique requires the worker to:

*S*: Stop before performing a task and to identify the correct component.
*T*: Think about the task, the expected response and actions required if the response does not occur.
*A*: Act by reconfirming the correct component and performing the intended function.
*R*: Review by comparing the actual response to the expected response.

The STAR process is widely used in the nuclear industry and will effectively contribute to an integrated safety management system by confirming that a task is safe to perform.

***Canada: Continuing education for radiation protection technicians (Pickering B NGS)***

At Pickering "B", the Health Physics Department has instituted a continuing education programme for its radiation protection technicians. At the start of each shift during pre-job briefings, a health physicist presents relevant topics and fields questions. The programme has a 3-fold benefit: the information presented is an extension of the radiation protection training; it delivers new information to experienced and recent graduates; and it provides the RP technician an opportunity to routinely meet with the site health physicists. This communication/interaction is essential in improving the day to day performance of radiation protection services.

***Lithuania: Training programmes at Ignalia NPP***

At the Ignalia NPP, it is recognised that proper training and education of workers is one factor to enhance radiological safety culture. Training and education of outside workers in the field of radiation protection is organised according to requirements set out in the Order of Minister of Health of the Republic of Lithuania. The established frequency of training is 5 years. Training programmes prepared for Ignalia NPP workers are also applied for the training of outside workers. The programmes are approved by the Radiation Protection Center and last about 30 hours.

***Romania: Radiation protection training of workers***

Station personnel have radiation protection qualifications according to the job requirements. There are four qualification levels with different skills and responsibilities, each which requires a refresher course every 5 years:

- Red: Untrained persons, who cannot enter or perform radiation work without special approval.
- Orange: Persons with basic radiological training and a requirement for obtaining initial access to any radiation area as well as for performing work in these areas. They are not allowed to perform activities in Zone 1 without a radiation protection assistant.
- Yellow: Persons given thorough knowledge for radiation protection, but with limited practical experience. These persons may perform radiation work without any assistance.
- Green: Experienced radiation protection personnel with thorough radiation protection knowledge. They may also act as radiation protection assistants for Red and Orange qualified persons.

## 4.4 Factors contributing to worker involvement

Motivation is an important prerequisite for worker involvement, and the factors and modes of behaviour previously discussed call for conditions and practices in the utility that will encourage and maintain involvement of both plant workers and contractors. In the long-term, this should lead to improved performance of the work-force and optimisation of radiation protection.

### *Role of management*

To fully involve workers in optimising radiological protection, it is important for them to see that management at all levels is committed to ALARA. It is also important that all levels of management apply work management to improve plant performance. If management is not concerned about the implementation of work management or the application of the ALARA principle, it will be more difficult to motivate workers to apply these approaches. Senior management is therefore an important link in work management and worker involvement. Their specific role should be to motivate workers, encourage their feedback and report this to top management. It is essential to show workers that they are not the only ones participating in the ALARA process and that management will listen to their suggestions.

As most of the outage work is often performed by contractors, it is similarly important to involve the contractor personnel in work management and radiation protection. Regarding management, there are two areas to be addressed:

- The management of the contractor should involve its personnel in work management and radiation protection.
- The management of the utility should:
  - Support involvement of contract personnel during the outage work and motivate contractors to co-operate in the work management and ALARA approach.
  - Review the contractor's attitude toward work management and radiation protection.

> ***France: Organisation of plant manager's visits on the floor***
>
> To facilitate and improve the efficiency of on-the-floor visits by managers, some EDF plants have developed an interview guide for managers. The guide is a check-list which recalls the main points to be controlled by the managers according to the reference RP internal guidance applied at the plants. Annual planning of the visit is set up to ensure that managers devote sufficient time to this activity.

### *Involving personnel in planning, preparation and ALARA review*

Generally, the person performing the job best understands the work and is best able to suggest changes to improve the work and reduce dose. To take advantage of this operational experience, workers should be integrated into the work planning and preparation phases. This will facilitate improvements in working procedures, scheduling, tools and techniques to be used, and harmonisation of actions to be performed. Work performance can benefit from the experience of personnel through post-job reviews and experience exchange (networking), and where appropriate, through feedback at specified stages (hold points) during a particular job. This will also improve workers' motivation as their knowledge and experience is requested, shared and utilised. An additional tool for collecting worker experience is the radiation protection "suggestion box", which can also be a useful motivational tool if feedback is systematically provided to those who submit suggestions.

In that most jobs are performed by contractors, the possibility of involving these workers in planning and scheduling is somewhat limited because they are normally not present on the job site before the beginning of work. However, these workers should be involved in job/task specific training as necessary, as well as in the post-job review so that their feedback can be obtained and utilised. This may require plant management agreement to pay contractors for their review time.

> ***Japan: RCP inspection (Ohi NPP)***
>
> At the Ohi NPP of Kansai Electric Power Co. Inc, the ALARA working group was established through the participation of Kansai's radiation control and maintenance departments, manufacturers and inspection contractors to address the reduction of radiation dose in reactor coolant pump (RCP) inspection activities. This group covers all aspects of RCP inspection, including the designing of equipment, inspection activities and administration. A plant management member was appointed leader of the ALARA working group.
>
> Based on questionnaires sent to some 50 workers involved in RCP inspection activities, major causes of high doses were extracted using the cause and effect diagram. These were further broken down to develop ALARA measures. Proposed measures were evaluated in terms of their reduction effect and cost efficiency and the following most effective measures were chosen:
>
> - Introduction of an ultrasonic cleaning unit for the decontamination tank.
> - Enhancement of shielding in the RCP inspection room (greenhouse).
> - Impeller shielding box.
> - Improvement of the internals hoisting device.
> - Introduction of automatic electric tools.
> - Enhancement of training.

### *Information and communication*

Workers should be regularly informed of management's ALARA programme goals and questions should be answered as soon as possible. This may be done by regular information sheets, handouts, posters, or on a case-by-case basis using, for example, information workshops. If goals are set for specific jobs, personnel should be informed of the achievements in meeting these goals, for example by the posting of charts, graphs and results on a periodic basis.

Prior to task performance, a short worker briefing provided by the task managers and/or radiation protection personnel can be useful to remind workers of the dosimetric objectives for the job, as well as of the job's main characteristics. Ongoing dose results associated with the outage should be displayed in a visible place, for example at the entrance of the guard house, reactor building or in the dressing room. Outage dose and job duration charts can also be posted on the shift outage turnover reports and discussed at each outage turnover meeting. Some key messages can be added to reinforce the motivation of workers to reach the outage goals. However, care should be taken to ensure that it will be not interpreted as checking performance or questioning qualifications.

Communication, information transfer and exchange of experiences within and between all levels will support the implementation of radiation protection procedures. This is particularly important for communication between utility staff and contractor personnel. For this purpose, it could be worthwhile to include utility personnel on contractor work teams if appropriate.

***France: Daily dose display, and booklets for contractors***

In France, all plants have implemented the daily display of the evolution of actual and predicted collective dose for the outage, and such practice is very well perceived by workers. This display is very often completed with information related to:

- The number of work accidents.
- The number of significant RP incidents.
- The number of internal or external individual contaminations.
- The main facts of the day.

EDF has also elaborated different guides for contractors summarising the safety and radiation protection rules to be applied at nuclear power plants:

- A national guide for all contractors (nuclear site access conditions, safety and radiation protection rules, recall of zoning, mandatory RP education, etc.).
- Local guides elaborated by each NPP for a specific outage (map of the site, phone numbers, FAQ on practical work organisation, alert signals, safety, RP and environment rules, outage flow chart and planning, etc.)

***Romania: Performance indicators – collective dose and dose accounting (Cernavoda NPP)***

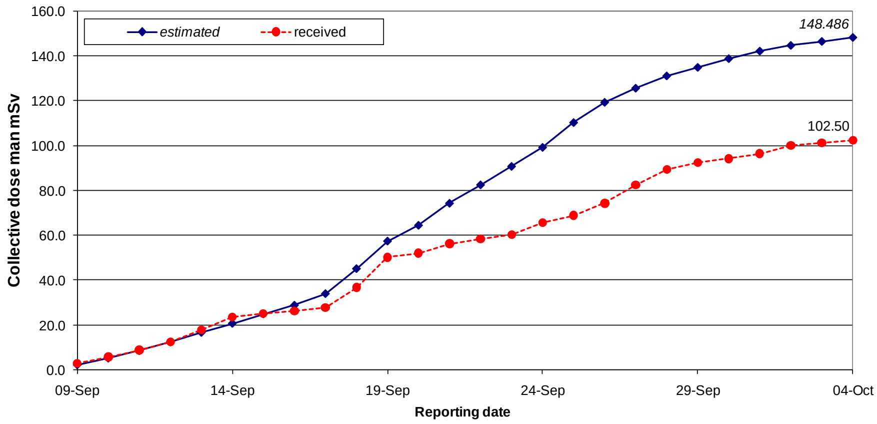
To improve the station and work group performance, plant performance indicators have been established at Cernavoda NPP that are related to the presence of ionising radiation and radioactive materials, including: i) collective dose, ii) internal dose (percentage from collective effective dose), iii) number of environmental events that have been reported to the regulatory bodies. These are assessed twice-monthly, monthly or quarterly.

Radiation protection awareness in the station and dose ownership were increased by placing specific types of information in key traffic areas of the plant: charts, bulletins, newsletters on radiation protection station goals, ALARA initiatives, RP policies and procedures. Moreover, before a planned outage, the radiation control service staff assesses all work plans involving radiological risks. The target value is established for the external collective dose for each task and for the entire planned outage. Each day the planned outage is printed and distributed by means of the following graphs and reports:

- Collective dose (personal alarming dosimeters – PADs) for all the tasks (daily and cumulative).
- Collective dose (PADs) for tasks with i) an estimated dose > 10 man·mSv, ii) an estimated dose < 10 man·Sv, and iii) for routines, support activities (with no estimated dose).
- Collective internal dose due to tritium intakes.

***Romania: Performance indicators – collective dose and dose accounting (Cernavoda NPP)*** (Cont'd)

Progressive evolution – Estimated/received external gamma collective dose (all jobs/tasks): planned outage, September 2006




***Sweden: Co-operation with contractors (Oskarshamn NPP)***

At Oskarshamn NPP, when a contractor is in the process of contract preparation for a job which might involve considerable individual and/or collective exposure, it is expected that estimates of expected doses as well as costs will be calculated and included in the information supplied to the utility for contract evaluation. To facilitate the contractor's job, and to assure accurate calculations, the contractor is supplied with all necessary data (photos, dose rates, drawings, etc.) The results of the contractor's calculations are reviewed by the utility radiation protection professional assigned to follow that particular job, and the contractor is required to explain how the proposed procedure will assure that exposures are maintained ALARA. By following this procedure, the contractor fully understands the problem and is able to propose solutions based on past experience, resulting in a better product for the plant and lower exposures.

***United States: ALARA briefing, outage guide and one-hour meeting with contractors***

At some US NPPs, workers assigned specific tasks are briefed by the Radiation Protection Shift Supervisors and by ALARA Group representatives. These briefings are documented and include:

- A review of work procedure.
- A review of work area conditions.
- A discussion on the necessary tools and equipment.
- A radiological briefing (review of all the specific requirements of the radiation work permit, and a discussion on personnel responsibilities for their conduct in radiation areas).

Additionally, at the beginning of the outage, the ALARA group spends 1 hour with the maintenance contractors in order to brief them on the outage goals. Each worker receives an outage guide, providing the phone numbers of the people responsible for the major activities, the outage objectives and goals, the daily meeting schedule, recommendations on security, quality assurance, industrial safety, scaffoldings, chemical control, housekeeping, radiation protection, etc. This guide also includes 25 maps of the major areas and the location of the main systems.

### *Additional incentives to motivate and involve workers*

In some cases, incentive programmes that recognise good ALARA performance can be used to motivate workers towards achieving dose reductions. Such programmes could recognise, for example, the best team or good performance in comparisons with results from previous outages or at sister-plants. Company awards can reinforce management's message to workers of the importance of a job well done. Although awards and incentives can also be used to encourage feedback from workers on making exposures ALARA, organisational structures should be in place to allow and encourage routine feedback as part of the job planning and review process.

***Japan, United States: Examples of incentive programmes***

In Japan, at some of the Tokyo Electric Power Company (TEPCO) nuclear power stations, competitions of good practice in work management and reduction of radiation dose and radioactive solid wastes have been held once or twice per year for over ten years. More than ten groups from various maintenance contractors participate in these competitions, which are hosted by the station Engineering Division Manager. Presentations of good practice are made by participants and awards for excellent presentations are made by TEPCO management. Also, the Hamaoka Nuclear Power Station of Chubu EPC has commended good practices for dose reduction since 1994 to promote workers' motivation.

In the United States, some nuclear plants have implemented some types of ALARA recognition programmes. Some of these programmes allow workers to collect "ALARA dollars" towards the purchase of merchandise. Other award options include company-provided trinkets (hats, shirts, pen-knives), prominent parking spaces or dinner certificates. One advantage of awarding merchandise over monetary awards is the length of time a worker will remember the award and thus its positive impact on attitude and plant ALARA culture.

***Russian Federation: Professional contest of health physics workers***

In Russia, one way of promoting the education and training of health physics workers is the professional contest. Health physics contests are organised every three years by the Russian utility, concern Rosenergoatom. The preliminary stages of the contest take place at the nuclear plants and include 20-30 local health physics workers who are competing in theoretical and practical disciplines. As a result, three best candidates are selected from every NPP. They participate in the final stages of the contest in personal and team nominations. The winners receive rewards such as laptop computers, digital cameras, etc. Moreover, workers are also strongly motivated by the fact that most winners have a successful career development.

## 4.5 Summary

While certain types of work planning and implementation may be carried out without the feedback of workers, the involvement of workers at all levels is one of the most important aspects of an effective work management 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 ensure the full involvement of workers, conditions should favour the creation and continuation of such involvement. It should also implicate workers at all the stages of a job (planning, scheduling, preparation, implementation, follow-up) and assure that there is a mechanism for matching individuals and their skill levels with appropriate tasks.

It is also important to improve worker performance for ALARA implementation. This requires an appropriate level of education and training to ensure that workers possess the correct tools and competencies. Involvement of all levels is also necessary: senior and mid-level management, job foreman, shift supervisors, etc. Good communications between different levels of the hierarchy and among the different disciplines should be a management priority. Finally, worker incentive programmes will help to improve and maintain worker motivation and involvement, and should pay for themselves in terms of savings in time, dose and costs, and in job quality.

# 5. WORK PLANNING AND SCHEDULING

*The planning stage is an essential period within which to implement work management actions and optimise radiation protection. Particular attention should be paid to the optimisation of outage duration. Work planning and scheduling should integrate radiation protection criteria and use feed-back experience and benchmarking to ensure that the most effective approaches are implemented. The planning stage should also integrate actions for the preparation of personnel, such as pre-job briefings or mock-up training, in order to improve worker performance and reduce occupational exposure.*

## 5.1 Introduction

Work activities in nuclear power plants must be carefully planned to ensure that radiological protection is optimised. Planning must recognise not only the sequence of job steps, but also their relationship and their multi-disciplinary nature. The scheduling of jobs in relation to each other, the identification of potential work interferences and hazards in the work zone, and the identification of dose intensive jobs are critical to the optimal use of resources and job success. The objective of this section is therefore to identify the key elements in planning and scheduling that permit work at nuclear power plants to be accomplished efficiently and the radiological protection of workers to be optimised. Technical and operational aspects are addressed in Chapter 6.

## 5.2 Optimising outage duration

The search for an optimal outage duration is based on two main fields of actions: the work selection process, which allows the elimination of all unnecessary jobs and, when all jobs have been selected, the elaboration of a tight schedule. These two aspects are developed below.

### *Work selection*

Selection of work to be included on a plant's outage schedule will determine the duration of the outage and impact dose and cost. The minimum outage duration is determined by the time taken to follow the outage critical path, for example, primary circuit depressurisation, reactor head dismantling, core off-load, performance of work, core re-load, reactor reassembly and repressurisation. All other tasks adding to the critical path will increase the outage duration. While additional work may be required to repair defects or fulfil statutory inspection requirements, any work other than the outage critical path should be evaluated and justified. Technically appropriate work which contributes to nuclear safety and equipment reliability should be scheduled and performed, as its avoidance or postponement may lead to unplanned shutdowns with their associated costs, risks and doses. However, other modifications, new installations or changes to existing systems may also be suggested by those initiating the work.

As all work should be evaluated to ensure that it is necessary, a key criteria will be the ability to make proper technical judgements regarding the value of proposed work and to distinguish between necessary and optional work. Within the organisation, there should be a multi-disciplinary group (distinct from the ALARA committee) that meets periodically to perform such evaluations taking into consideration the plant-specific criteria for the maintenance programme. This group should make "yes/no" decisions on the work to be performed, having in mind that performing unnecessary jobs costs money and causes unwarranted radiation dose.

In order to reduce the work load during the outage period, planned preventive maintenance (PPM) during operations may be considered, if appropriate. However, the possibilities for this depend on the actual design of the various systems with respect to redundancy and diversity, especially those concerned with safety. Consideration of systems for which PPM may be performed will also depend on the radiological conditions.

Finally, consideration should also be given to developing a multi-year approach to work that addresses long-term improvements in plant radiation levels, for example through the use of engineered plant modifications, improved work practices and other considerations. Such an approach allows a long-term plan of work addressing identified improvements to be undertaken in a stepwise fashion and included in a structured manner in the plan of work for any individual outage.

***Sweden: Use of planned preventive maintenance (PPM) during operation (Forsmark NPP)***

At Forsmark NPP, PPM on safety related systems may only be performed if the following conditions and restrictions are met:

- The technical specifications specifically permit PPM for the system and time duration.
- Only one (of four) trains may be impacted at a time, the other three trains being operational.
- The work is performed in accordance with operational directives.
- If during PPM, faulty components (due to any unanticipated reason) are discovered, specific criteria for repair have to be met, as specified in the Technical Specifications.
- Also in the event that faulty components are found in a redundant system in any other train than the one in which PPM is performed, specific criteria for repair have to be met, as specified in the Technical Specifications.
- The mode of operation of the reactor may be changed during PPM.
- PPM may be performed for a total duration of maximum 60 days per year.

### *Work scheduling*

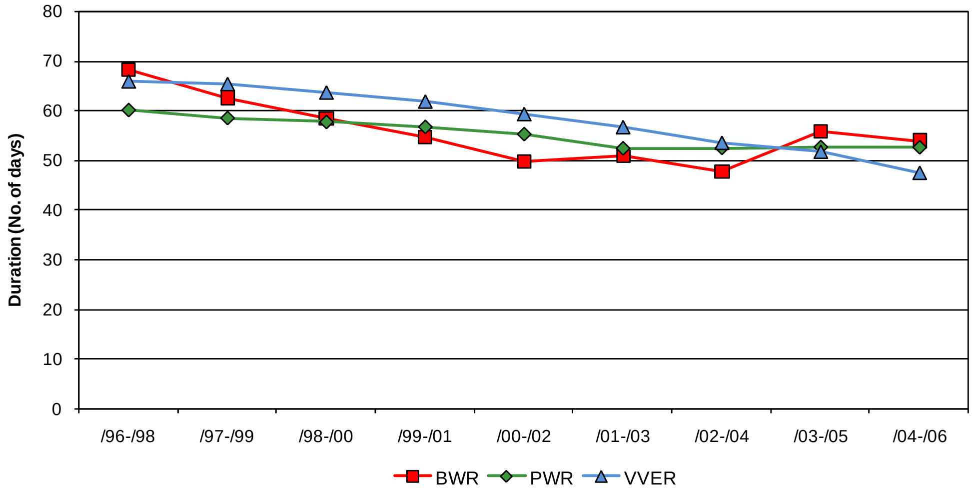
When all the work and the corresponding schedules are known, potential problems can be anticipated in the planning stage and corrective actions taken to optimise the work schedule. When establishing the overall schedule, it is important to bear in mind that a job will often take as much time as it is allocated in the schedule. A loose timetable will increase the likelihood of all jobs and tasks taking more time to finish than an optimal time table. Thus, by simply optimising the timetable, time, dose and cost can be saved. It is also important to recognise that if an outage is prolonged by a single job, it will cause excessive radiation doses because other jobs will also proceed more slowly. If one unexpected job causes significant delay to an outage (for instance, because spare parts have not been delivered on time), efforts should be taken to postpone the work to a future outage if the system can be left in a safe mode and approved by the safety authority based on dose reduction projections.

### *Outage duration*

The search for an optimal outage duration based on work selection and optimal schedule has been successful in most utilities and for all types of reactors. Figure 4 shows the evolution of the three-year rolling average of outage duration for PWRs, BWRs and VVER (ISOE, 2008). On an average, the duration of outages is now around 50 days.

Several utilities are also experiencing the implementation of short outages dedicated only to refuelling and with only a few maintenance works (e.g., 7 days outage at Olkiluoto NPP, Finland), followed the year after by a more extensive outage where all maintenance works are performed.

Figure 4. **Average outage duration by reactor type**




***Finland, France: Outage types and durations***

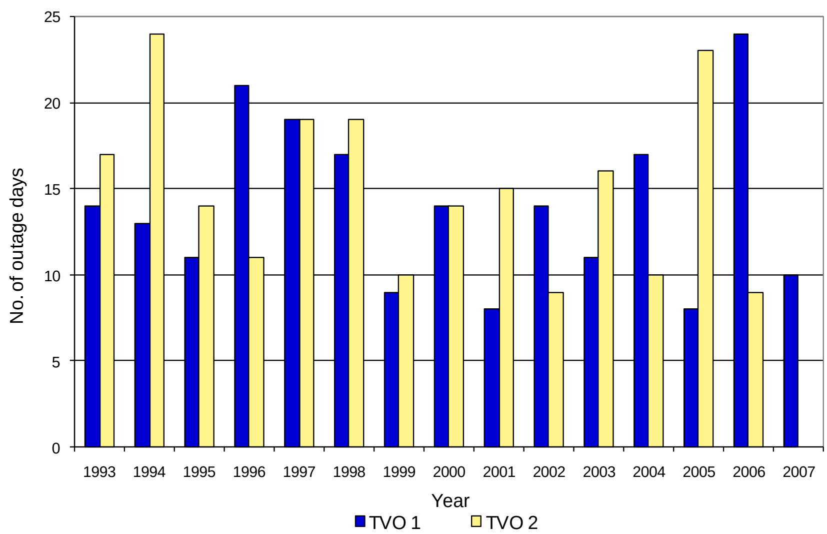
In Finland, planned outage types at Loviisa NPP include:

- Short refuelling outage: planned duration 18 days (every other year).
- Normal refuelling outage: 24 days.
- Inspection outage: 34 days (every fourth year).
- Extended inspection outage: 42 days (every eighth year).

The outage policy at Olkiluoto NPP is:

- Short refuelling outage: 7 days.
- Long service outage: 14-21 days (normal, long).
- Annual outages after each other with short interval.

**Outage duration at Olkiluoto NPPs**



*Finland, France: Outage types and durations* (Cont'd)

In France, three types of outages exist for EDF plants:

- Short refuelling outage: around 3 to 4 weeks.
- Normal maintenance outage: around 6 weeks.
- 10-year maintenance outage: around 14 weeks.

There is a turn-over between the short and normal outages; the delay between 2 outages is usually 12 months for 900 MWe plants and 18 months for 1 300 MWe plants.

## 5.3 The job planning process

### *Work planning*

Three types of work are traditionally understood for fuel outages: i) planned work ii) unplanned work which is not planned in advance and can therefore cause delays and iii) emergent work.

*Planned work*

Effective work planning is essential to optimise radiological protection and minimise operating and maintenance costs. It is important not only for outage planning, but also for "at power" work to ensure that costs and doses are optimised throughout the power cycle. Integrated work planning allows proper review of work in radiation areas and provides an opportunity for necessary controls to be factored into work plans.

One approach to the process of integrated work planning is to assign maintenance planners, rather than radiation protection personnel, the responsibility for radiation protection planning down to the job level. This puts the responsibility in the hands of line management closer to the actual work and fosters interdisciplinary communications. As part of the multi-disciplinary planning team, it is, of course, essential to maintain the involvement of radiation protection personnel in this process, for instance, to provide input as to radiological conditions at the work site, feedback experience as to contractor and material selection, and review ALARA of procedures. This approach is currently used in many nuclear plants worldwide.

An important consideration for the planning team is the review of lessons learned and the inclusion of corrective actions in the planning process (see also Chapter 8). Planners should use the best available sister plant information on source term, duration and crew size in planning similar work at their unit to increase effectiveness. Non-optimal information can lead to extra shielding, additional time, etc.

The physical location of the job planning team is also a factor in the success of the planning process. While much communication can take place electronically, situating planners together in one location opens communication lines and enables more efficient interfaces. Reinforcing the multi-disciplinary nature of work management, most plants which have been successful in incorporating effective radiation protection consideration into their planning process have also integrated radiation protection personnel into the planning organisation.

*Unplanned and emergent work*

Unplanned work refers to plant equipment repairs and work not previously identified or planned as part of the outage work scope and subsequently discovered during the outage, for example, unplanned work required to repair a BWR dryer crack discovered after unit shutdown and vessel head removal. Emergent work refers to new issues or concerns identified after the start of the outage, resulting in an expanded work scope, for example, the need to plug selected steam generator tubes based on eddy current testing results.

In both cases, utilities should define in advance the policy to be adopted in the case that unplanned or emergent is identified during the outage. This could include, for example, determining if the identified work must be addressed immediately during the outage or if it can be postponed to next outage or the inclusion of a contingency in the schedule/budget for undertaking such necessary work.

***Radiological protection aspects of work scheduling***

Careful work scheduling and scheduling reviews are important in maintaining doses ALARA. The majority of dose-significant maintenance work is performed during the refuelling outage in PWRs and BWRs, and during maintenance outages in CANDUs, when radiation fields are substantially less in most places than during power operation. Other opportunities for maintenance work occur, however, during power downs used to perform control rod sequence adjustments, when dose rates are lower in areas such as BWR steam-affected locations.

Scheduling work during a particular period within the outage is also important. Doses can be saved without any costs by putting jobs in an optimal order and performing them at the right moment. For example, if the timetable does not require that jobs on radioactive systems be done immediately at the start of the outage, then they should be scheduled later when dose rates are lower. Coolant purification and natural radioactive decay will contribute to this effect. Additionally, jobs should be scheduled, whenever possible, during periods when the system is water filled. Even if the process water is contaminated, it absorbs radiation. The dose rate at the surface of a pipe, valve or pump is almost always much lower when the system is full than when it is drained. It is usually assumed that the presence of water will reduce dose rate on the order of 30%. This is important for work done close to pipes, for example work with insulation, shielding and scaffolding. Flushing of systems, where possible, can also contribute to dose reduction by removing hot spots or crud deposits.

During planning, it is important to have a clear understanding of all work to be done in an area, and how various jobs are related. In order to take advantage of arrangements for other work about to begin, in progress or recently finished, to avoid situations where one job creates a radiation problem for an adjacent work crew or to prevent congested areas that diminish safety and productivity, planners should consider “time-based”, “resource-based” and “area-based” scheduling:

- Time-based scheduling is the traditional outage schedule with planned work assigned time blocks on a master refuelling outage schedule. The timeline considers planning issues including critical path work, need for maintenance of secondary containment, decay of short-lived noble gases and fuel movement window.
- Resource-based scheduling aims to take advantage of local arrangements or infrastructure for multiple activities, thereby saving dose and cost, e.g., the reuse of contamination containment or previously erected scaffolding for multiple tasks.
- Area-based scheduling evaluates the type and concentration of work in defined sectors. This is accomplished by dividing work areas into grids depicting different kinds of work, which can be overlaid to allow schedulers, planners and work foremen to visually depict all work in each grid sector. This can be performed using computerised systems, or engineering maps.

***Work planning tools***

Advanced imaging tools provide a good visual reference for work planners, radiation protection pre-job planning and worker pre-job meetings. Many plants have identified the need to record and access images of various plant areas and components not normally accessible due to plant operation and/or high radiation levels. A centralised image database provides consistent information for job planning, minimising visual inspections and reducing redundant and inconsistent individual efforts by various groups to record photos or videos of selected components whenever work is being planned. As many engineers regularly photograph plant items with digital cameras, these files should be appropriately named and stored in a central information management system to avoid the need to re-photograph the item when planning the next round of work.

The following advanced imaging tools are being used worldwide to better view and assess the working areas and to better take into account the potential environmental constraints which might have an impact on the job performance:

- Computer-based multimedia.
- Videodisk-based image storage and retrieval systems.
- Video and digital photography.
- Image transmission technology.
- Photogrammetry:
  - Gamma camera radiation-field photography.
  - CZT (Cd, Zn, Te) detector (multi-spectrum gamma analysis).

Such technology and information is particularly important to use or collect during the commissioning of new plants.

In plants where a remote monitoring system (RMS) has been installed, the videos recorded by these systems can be used in the job planning phase. In addition, many plants used 3-D computer aided design (CAD) models during the design phase. Older plants also employ laser scanning and 3-D computer techniques to characterise and verify the actual plant environment, and minimise work time. These tools should be used in the work planning process wherever available.

***France: 3-D modelling software***

EDF has developed two main types of 3-D modelling software which can be used in work planning:

- PANTHERE-RP: A static simulation of areas presenting the dose rates of the main components. The software is used to estimate the contribution of each component to the ambient dose rate in view of optimising shielding, as well as for the conception of new installations and modifications.
- ADRM: A dynamic simulation where the tasks can be simulated in time and space. With this software, it is possible to simulate how large components can be removed and replaced (e.g., heat exchangers). The area models are based on real data coming from on-site laser scanning.

***Germany: System of 3-D pictures (Phillipsburg NPP)***

Because of very high dose rates during full power operations, many areas inside the controlled area cannot be accessed, or only on a limited basis. Technical evaluations in these areas are quite difficult to carry out. One possibility to minimise the access to high dose rate areas is a specific "room information system" inside KKP1 and KKP2. This computer-based programme consists of a 3-D version of these rooms under normal circumstances are non-accessible areas inside in the unit. Technical evaluations can be done in many cases on a "virtual" basis without unnecessary exposure to high dose rates. In order to make this system operational, 3-D laser scans of these areas where taken during prior outages. Within these laser scan files, distances for planning options can also be measured with an accuracy of about 2-3 cm for a 10 m distance.

***Spain: Mapping database (Almaraz NPP)***

At Almaraz NPP, the Environmental and Radiation Protection Department has a comprehensive mapping database covering the radiological characteristics of the two units: 300 maps of the rooms are computerised, including for each area, recorded dose rates at 3-10 measurement points (ambient and in contact with equipment) as a function of the different states of the unit before and during unit outages. The database can be read from the radiation protection room at the entrance to the controlled area.

***United Kingdom: Health physics information sheets (Sizewell B NPP)***

Sizewell B has produced "Health Physics Information Sheets" that contain a photograph of the valve, weld or component in question, a map showing where the plant item is located, a brief summary of local radiological conditions in various plant states and advice regarding optimal work windows to minimise dose. Originally intended to help work parties find the job location, they are used extensively by engineers when planning jobs.

***Size and management of work teams***

The scope of work, as well as workplace factors, will impact the size of the team required to carry out a given job. The optimum size of a work team is the smallest number of workers that can perform the work according to the work plan and schedule. Generally it can be said that the fewer the number of workers, the smaller the collective dose. For instance, if the number of workers is doubled, the duration of the work will be shorter, but it will not be halved. Adding more workers will increase the total number of working hours thus increasing the collective dose and cost. Therefore, in general, no more than the necessary minimum number workers should be assigned to a job, accounting for the need to not exceed designated dose constraints, as well as the impact of other workplace factors such as noise and heat.

Another example of how the collective dose will increase with the number of workers is the exchange of workers. The dose received from a job is the sum of three phases: 1) doses received in transit to the work site, orientating and putting the tools in order and getting started, 2) doses received while performing the job, and 3) doses received while finishing the job, securing the work site, removing protective equipment and leaving. The dose in phase 2 is relatively constant and independent of the number of workers exchanged, but doses in phases 1 and 3 will increase each time a worker or work team is changed. The exchange of workers should be used only when it is necessary for controlling individual doses, or for managing other work place factors.

***Selection of contractors***

As most outage work is often performed by contractors, it is important to have a process that allows the identification and selection of appropriate contractors when required, based on the work to be performed. Such selection should be based on several criteria including methods proposed by the contractor to optimisation radiological protection during the work and their past performance. Since interaction between the utility and the contractor is one of the most effective ways to optimise the job design, it is important that the contractor is brought in at the design stage, with sufficient time before the work is to be performed (see also Chapter 4). A consideration in the selection of contractors is who was used previously and the level of success.

*France: Experience in selection of contractors*

At the planning stage of new maintenance operations, EDF selects the contractor based on several criteria, including the demonstration that they have implemented a study to optimise radiation protection of the tasks (time, dose, cost). After the contractor's selection, several mandatory information exchange meetings between the contractors and the utility take place to continue the task design. The documents to be produced by the contractors include: a radiological risk analysis (external and internal exposure, contamination transfer, etc.) and a radiation protection procedure.

## 5.4 Work process control systems

Work process controls are critical to the success of well planned outages. Computerised work process control systems assist with the planning process by providing job-related information, including the authorisation process of the different departments, as well as scheduling and work-site requirements. They can also be operated as a tool for working crews, providing guidance and giving knowledge of the state of the operation to all groups involved (Chapter 7). This may be supported by information from a radiation protection database covering dose rate and other parameters influencing the radiological risk.

Such a system is of great advantage during the planning and scheduling phase as well as when dealing with unexpected jobs. Experience in most plants is that even in the case of unexpected high-priority jobs, an ad-hoc planning/scheduling strategy must exist to assure adequate work results and to avoid rework. Computer-based systems facilitate quick planning/scheduling and can also include the radiation work permit, using the same database of information (component, site, working conditions) and incorporating information of similar operations done in the past.

### *Radiation work permits in work planning*

The radiation work permit (RWP) is usually a written and approved document establishing all the radiation protection measures necessary for safe performance of a specific activity or job considered as "radiation work" and addressing the radioactive waste aspects related to the activity. These permits, given to workers by the radiation protection staff prior to starting the job, usually contain the following information: date and time of the job, number of workers, description of the job, predictive dose, dose rates, surface and atmospheric contamination levels, protective suits needed, biological shielding, type of radiation protection monitoring for the job, etc.

There are several advantages associated with the use of the radiation work permit. Firstly, the task of producing them requires planning and anticipating the radiation protection that will be required. In addition, the radiation protection staff is informed of all planned jobs in the controlled area and can monitor the progress of work during the outage. In the field, the information contained into the permit help the team leaders and the workers to be aware of the radiological conditions at the work site. The radiation work permit can also be used check (and hence limit) entries, especially since the expiry dates of the permits are read automatically when the workers enter the area. Lastly, it can be used as a data base for collecting the dose associated with the specific jobs (see also Section 7.3).

***France: PREVAIR software***

In France, EDF has developed the PREVAIR software for the elaboration of predicted dose estimates associated with each job. At the end of the preparation phase, this software allows the printing of a radiation work permit (RTD), with the following information:

- Predicted collective dose for the job.
- Predicted mean individual dose for the job and per day.
- Predicted dose rates at the workplace.
- RP actions to be implemented.
- Specific instructions to be fulfilled if the actual dose rate or the actual collective dose is significantly different from the predicted ones.

A bar code associated with each RTD is used to check the entrance to the controlled area (if the code is not recognised by the system, the entrance is refused), to modify the alarms set on the operational dosimeter and to assign the dose to the right job in the outage dose database when the worker exits the controlled area.

***Romania: Radiation work permit system (Cernavoda NPP)***

At Cernavoda NPP, the pre-job and post-job RWP analyses involve personnel from all the plant work groups as well as the ALARA Committee. Radiation Control Service personnel verify the observance of radiation protection requests as they are mentioned in the RWP. RWPs with more than 10 man·mSv estimated collective dose will be reviewed by the work groups' ALARA Co-ordinators in order to identify options to reduce exposures. If necessary, this form will be sent to the ALARA Technical Committee to be reviewed (for activities with more than 20 man·mSv estimated collective dose). After the work is completed, a radiation work permit report will be sent to the work group ALARA staff to justify, if necessary, the discrepancies between estimated and received doses.

## 5.5 Job planning for high dose jobs

### *Identifying and tracking high dose jobs*

High dose jobs are those jobs which should primarily be included in the radiation protection control system. As such, it is necessary to identify these as part of work planning, to put in place processes for tracking them to ensure that protection of individual workers is optimised and that occupational dose limits are not exceeded, and to develop contingencies in case of unexpected events during the work. In Table 2, typical high dose jobs at light water reactors have been listed as an example.

Table 2. **Typical high dose jobs at light water reactors**

| *"Top ten" high dose jobs* | |
|---|---|
| Control rod drive maintenance*<br>In-service inspection<br>Main steam isolation valve maintenance (MSIV)<br>Pressuriser valve maintenance<br>Reactor water clean-up pump maintenance (CUW)<br>Recirculation pump maintenance and replacement | Calibration and repair of:<br>In-core radiation monitors (IRM)<br>Transversing in-core probes (TIP)<br>Residual heat removal system valve maintenance (RHR)<br>Safety relief valve maintenance* (SRV) |

* *Some plants move/conduct this work off-site by contractor.*

Table 2. **Typical high dose jobs at light water reactors** (Cont'd)

| *Other high dose jobs* | |
|---|---|
| Cavity decontamination<br>Chemical and volume control system maintenance<br>Insulation removal and replacement<br>Instrumentation calibration and repair<br>Local leak rate testing<br>Operation-surveillance routines and valve line-ups<br>Plant modifications<br>Radioactive waste system maintenance<br>Radioactive waste processing, storage, shipment<br>Reactor coolant pump maintenance<br>Reactor head work<br>Refuelling | Calibration and repair of:<br>Power range monitors (PRM)<br>Start-up range monitors (SRM)<br>Reactor water cleanup heat exchanger maintenance<br>Scaffold installation and removal<br>Snubber inspection and repair<br>Steam generator maintenance<br>Steam generator replacement<br>Torus inspection and repair<br>Weld overlay job of recirculation system piping |

One useful approach to take advantage of the many years of collective experience in the nuclear industry for critical jobs is to use the ISOE occupational exposure database and communications network to "benchmark" the collective dose of a job against that seen at other plants around the world. An example of an RP information report which can be found on the ISOE Network website is presented in Appendix 2.

***ALARA preparation for high dose jobs***

Although a search for dose reduction has to be performed for all jobs, it is particularly important to perform detailed and systematic ALARA analysis in terms of collective and/or individual doses for high dose jobs. This type of analysis should include a systematic review of all the possible actions available to reduce exposures. Usually, ALARA check-lists are used by job planners in order to identify possible protection actions and/or dose reduction options (Appendix 3). Examples of questions which may be integrated in more detailed check-lists include:

- Is the scheduled time sufficient and optimal?
- What support services are needed and when (scaffolding, shielding, insulation work, etc.)?
- Is the manpower sufficient and optimal?
- What doses can be expected (based on internal and external experience)?
- Is there another similar component that could be inspected in place of the originally planned "hot" one?
- Can the component that needs service be moved to another place with a lower ambient dose rate for repair and servicing?
- What personal protective equipment should be used? What was used before and what were the benefits?
- What dose reduction techniques can be used (e.g. system flushing)? What was used previously and what was the result?
- Which contractor was used last time? Try to get the same contractor and even the same workers if they did a good job. They know what to do and how to do it.

***Canada: Implementing radiation protection oversight (Pickering B NGS)***

At Pickering B NGS, during high radiologically hazardous work, the governing body for station nuclear procedures requires that, as part of the High Hazard Procedures, a Radiation Protection Oversight must be assigned to every High Hazard Job. The RP Oversight is an experienced qualified radiation protection co-ordinator or a station health physicist. The RP Oversight does not actively participate in the execution of the high hazard work but oversees the work as it progresses. The job of the RP Oversight is to ensure strict adherence to Station Procedures and the High Hazard Workplan, and as an impartial observer, foresee procedural or operational disconnects and provide this information to the workers.

***France: Identification of high dose jobs; heat insulation workers***

In France, a detailed and systematic risk analysis has to be performed before all jobs. This analysis has to review the risk of external exposure (potential neutron exposure, extremity doses, etc.), internal exposure (potential presence of alpha particles, etc.) and material contamination. Such an analysis is essential for identifying high dose jobs and other risks.

As a specific example, among all EDF workers, heat insulation workers receive the highest average individual radiation dose. The Nuclear Operation Division's ALARA project has been working on this issue for several years and has obtained encouraging results: in 1997, a set of "good practices" was drawn up in order for sites to minimise radiation exposure for this particular worker category. These good practices set out the measures to be taken in order to minimise dose (type of heat insulation, screens to be used for each component, work time, etc.) Once this approach was implemented, average annual individual dose fell from 6.45 man·mSv in 1998 to 3.84 man·mSv in 2005, equivalent to a drop of 40%. In order to achieve further improvements, this purely "equipment-based" approach must now be followed up by a more "in depth" action by bringing changes in the job.

***Japan: Exposure reduction (Fukushima Daiichi NPP)***

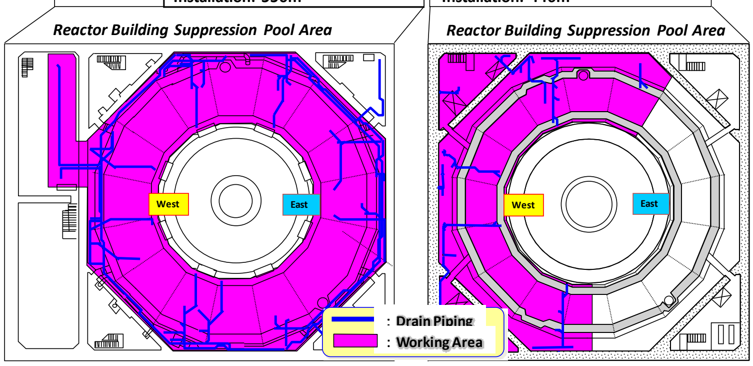
The replacement of drain piping at the Fukushima Daiichi Units 4 and 5 was performed under high dose rates. To reduce doses, the following exposure reduction measures were executed:

- Flushing of pipes.
- Installation of temporary shields.
- Treatment of the blow down water (Unit 4).
- Implementation of remote dose monitors.

Regarding remote dose rate monitoring, workers wore wireless dosimeter APDs (Alarm Personal Dosimeter) in addition to a usual electronic personal dosimeter, especially during high dose rate work. Moreover, measures were taken to monitor the dosimeters worn inside the protective clothes on top of regular clothes.

**Removal work scope of equipment and floor drain piping**

| Unit | 4 (BWR4) | 5 (BWR4) |
|---|---|---|
| Schedule | Nov.22, 2002 - May 21,2003 | Jan.20, 2003 - Sep.26, 2003 |
| Work | Removal: 415m<br>Installation: 556m | Removal: 446m<br>Installation: 446m |



## 5.6 Benchmarking

Making good use of available data and operational experience during work planning will optimise the radiological protection of workers and increase overall work performance. Many types of information sources can be used, such as post-job reports, outage critiques, and deficiency/exposure reduction item tracking lists. Other valuable resources which are available for radiation job planners include job history files, photo libraries, information databases and other utilities who have previously performed similar work (see also Chapter 8).

Benchmarking during the planning stages allows good practices to be identified and implemented. Benchmarking which takes advantage not only of historical information but also current experience from other utilities is a key part of effective planning and good performance. Benchmarking not only allows numerical data to be exchanged, but it is also closely linked to networking, where contact between utilities leads to the exchange of work practices, equipment and technology. This sharing and pooling of experience across the industry is an important factor in minimising outage duration, as key tasks are often performed by the same contractors. If they can adopt similar work practices at all plants, the job will be easier and quicker than if they had to learn a new way of working at each plant.

Information exchange with other utilities by means of regional or global user networks, such as industry-supported networks, ALARA user groups and the global ISOE programme is one of the best ways for sharing ALARA experience and good practice. Such exchange throughout the nuclear utility industry has been universally endorsed and well supported, particularly through programmes such as ISOE. Participation in industry owner's group meetings allows the exchange of dose information, lessons learned and plant-specific regulatory issues. Utilities can also send personnel to visit other facilities and benchmark their processes against those identified as industry leaders or to learn from problems encountered at these plants. One convenient and cost effective method of gathering useful information is telephone calls or emails to other nuclear power plants.

Procedures, training documents and co-workers can provide detailed plant specific information for radiation protection planning. People are sometimes one of the most frequently overlooked or untapped information resources. Identifying the right people to contact for certain information usually takes time but becomes easier the longer an individual is part of an organisation.

***ISOE: International benchmarking using ISOE***

The ISOE programme, which operates the world's largest database of occupational exposure data for workers at nuclear power plants can provide various types of dose trend analyses by job type and sister-plant. This includes annual occupational exposures for individual units (normal operation, refuelling/ maintenance outage, forced outage), individual annual dose distributions for each unit or site, job specific exposures, plant configuration information (start-up/shut-down procedures, water chemistry, ALARA programmes, etc.), and specific information for particular tasks, jobs, incidents, etc. which are interesting from an exposure reduction perspective.

The ISOE Network website (www.isoe-network.net) provides a focal point for ISOE resources, including the ISOE database, ISOE reports, a users forum for on-line exchange of information, and contact information for ISOE members worldwide. ISOE also conducts annual ALARA symposia around the world to allow direct interaction and exchange of experience amongst RP professionals.

***Japan: Benchmarking visits***

Representatives of Japanese utilities and other organisations related to radiation protection conducted benchmarking visits to the United States and Europe between 2005 and 2007. They visited the US NRC and selected nuclear power plants in the United States (Fermi, Limerick, Susquehanna, Dresden and D.C. Cook), STUK in Finland and ASN, CEPN and EDF in France. This permitted exchange of information on new technologies such as remote monitoring systems, the importance of top management commitment and of co-operation between maintenance and radiation protection personnel, etc. Japanese utilities taking such information into consideration when making efforts to reduce exposures.

***Russian Federation, United Kingdom: Using ISOE in benchmarking analyses***

In Russia, a special workshop was organised in December 2005 at the All-Russian Research Institute for NPP Operation (Moscow) with the aim to provide better comparison and analysis of ISOE1 data for VVER units. As a result, the technical manual "Basic principles of ISOE1 data standardisation for operational VVER type reactors" was prepared and issued.

In the United Kingdom, the radiation protection regulations require utilities to use dose constraints at the planning stage of tasks. The constraint should be set at a level of individual, and sometimes, collective dose that represents "good practice". If the work proposals indicate that a dose higher than the constraint will be received, the utility must review the proposals to ensure that all reasonably practicable measures have been used to keep doses ALARP.

To identify a suitable dose constraint for the first reactor pressure vessel (RPV) head replacement at Sizewell B, staff used the ISOE information sheets and ISOE 1 database to rank previous utilities performance for this task. The dose constraint was then set at the upper decile value for this distribution. The upper decile plants were also identified, to enable direct contact to be made to discuss various aspects of this job.

The ISOE databases are not just for use by RP staff. They also contain information of direct relevance to outage managers such as number of people on a job and number of man-hours required to perform each task.

***United States: Historical ALARA database***

A database of historical ALARA experience and good practice (1962-1986; complied by Brookhaven National Laboratory under NRC contract – turned over to NATC in 1995), created from information taken from journal and proceedings articles and categorised by key words, exists at ISOE-NATC.

## 5.7 Personnel preparation

One major planning task is the selection of appropriate personnel. It is of major importance to have motivated, highly skilled workers who are experienced at performing the anticipated or similar jobs. A motivated, trained and experienced nuclear worker will do the same job with higher quality and within a shorter time than a specialist who is not used to working under controlled area conditions.

To develop an experienced team of qualified workers requires a significant amount of training. This training is twofold. All workers should receive education and training to implement the ALARA approach during the course of their work (see Chapter 4). In addition, as part of work planning, work teams should receive specific pre-job training on the work to be undertaken, using actual (or similar) tools and equipment and realistic protective clothing in order to improve job performance. One efficient technique for reducing the exposures from high-dose jobs is to familiarise workers with the work by undertaking multiple entries into the radiological controlled area over a series of outages.

It is important for the workers to be aware of outage goals, as well as the estimated doses for their jobs. Prior to the work, a short briefing provided by the task managers and/or radiation protection personnel can be useful to remind workers of the dosimetric objectives for the job, as well as of the job's main characteristics. This can also be an occasion to spread messages as to the importance of quality, the fact that radiation protection is a "quality issue", the need to avoid rework, etc.

***United States: Personnel preparation (Cook NPP)***

At the American Electric Power's Cook nuclear power plant, radiation protection technicians have been assigned specific tasks and areas for several outages in a row, thus familiarising them with the area and the work. This has been particularly effective in high dose rate areas such as the upper and lower containment, and particular areas in the auxiliary building. Sending radiation protection technicians to the vendor (Westinghouse) for training with work crews for particularly high dose jobs, such as reactor coolant pump repair, has also proven effective at building interdisciplinary communication ties on the work crews.

### *Mock-up training*

An important approach in personnel preparation is the use of mock-up equipment for training on certain types of work, such as installation of ultrasonic scanners or temporary shielding, removal and replacement of control rod drive mechanisms, valve disassembly/re-assembly or other dose-intensive jobs. Training on mock-ups allows workers to repeat anticipated tasks in a clean environment. This allows workers to become familiar with the maintenance or inspection process, special tools or supporting devices, or difficult working conditions before entering radiation areas, thereby increasing the efficiency of work in the radiation area. By training several workers for the same job, those with the highest performance can be given the most delicate jobs. In all cases, trained workers will perform the actual job more efficiently, in a shorter time and with lower doses.

Proper execution of a mock-up training plan includes three important aspects as inaccurate mock-up training can be worse than none at all:

- The mock-up replica should be full size, if possible, and in an environment similar to the field location.
- The physical constraints and conditions (scaffolding, lead shielding, insulation etc.) should be installed as for the actual work.
- Full personal protection equipment, respiratory protection, communications and access constraints must be also simulated.

In Europe, many PWR plants have on-site steam generator channel head mock-ups to train utility as well as contractor personnel. Even some specialised nuclear service companies have their own mock-ups to train their staff.

***Belgium, France, Hungary, Japan, Korea: Use of mock-up training***

In Belgium, at Doel NPP there is one steam generator mock-up per fleet, one reactor vessel head mock-up, two mock-ups for the cleaning of the splits, three mock-ups for jobs on the thermocouples and three mock-ups for the coupling/uncoupling of the rod cluster control assemblies.

In France, a good example of the effective use of mock-up training is the CETIC Training Centre, run by EDF and AREVA. This 4 000 $m^2$ facility houses full-scale mock-ups of all major PWR components (pressure vessel, vessel head, steam generator, pressuriser, reactor coolant pumps, refuelling machine, fuel assemblies, reactor cavity, etc.) and is used for worker training and new equipment testing. As a specific example, the training of "steam-generator jumpers" to perform tube plugging work reduced the worker's time in the channel head from 45 seconds to 20 seconds. For such jobs in high dose rate environments, studies indicate that adequate mock-up training can reduce the time in the high dose rate environment by up to 40%.

**EDF CETIC fuel loading training**

In Hungary, the Paks NPP has a training centre equipped with most of the main components of a VVER unit. About 15 persons work full-time at the training centre. It is unique due to the fact that the components are exactly the same as those in the controlled area, as they were originally to be used in plants (which finally never became operational). In particular, there is a steam generator, a reactor vessel, half of a reactor vessel head, a primary pump, internals assembly, an isolating valve, a non-destructive testing laboratory, electrical equipment, etc. These components are used for the practical training of workers (utility, contractors) at their arrival in the plant and for refresher training courses once a year. A maximum of 10 persons (5-6 per component) can train at the same time. Moreover, these mock-ups are used to prepare maintenance works, to validate new techniques, new components and new devices in an ALARA perspective.

In Japan, a mock-up facility is operated by Kansai Electric. Such mock-ups are also used to test newly developed tools or devices before use at actual work sites, thus saving time and optimising use and functionality before an actual outage. Many plants have their own mock-ups or training facilities which are effectively used to acquire appropriate skills.

In Korea, mock-up training is undertaken 2-3 times to familiarise workers for high radiation work, including entry into the steam generator and pressuriser. Such training favours reliable and speedy work, consequently leading to a decrease in collective dose. A variety of mock-up tools have been prepared for training including a replica of the steam generator chamber for nozzle dam installation, an in-core instrument seal table for replacements, reactor coolant system boundary valve for lapping and pressuriser internals for heater removal.

***Canada: SFCR training mock up (Pickering B NGS)***

The single fuel channel replacement (SFCR) is a complex project which involves many specialised people and tooling. It is a dose intensive job because the bulk of the work is performed on the reactor face where the dose rates are generally high. Along with shielding, minimising the personnel time in front of the reactor face is an effective technique to keep doses ALARA. In order to achieve this, extensive training and rehearsals were carried out at a mock-up facility specifically designed for the work. This not only reduces potential for human errors, but also helps in the execution of the work quickly and more efficiently, thus, reducing time spent on the reactor face.

***Japan: Mock-up training in the Ikata 1 core internals replacement***

At Ikata 1 of Shikoku Electric Power Co., Inc., the following mock-up training was performed for the core internals (CI) replacement work:

- Removal of support column flange bolts of the existing upper CI.
- Performing clearance measurements at the outlet nozzle and radial support of the new CI.

| Relevant activities of the CI replacement | Training description | Place of training | Date of implementation | Persons trained |
|---|---|---|---|---|
| 1. Separation of the T/C support columns | Train personnel in cutting the T/C conduit tube, removing the T/C support column flange bolt and attaching a plug to the T/C support column for tip-over prevention. | Ikata NPP | 23 August-<br>2 September 2004 | 28 |
| 2. Removal of components from the existing CI | Train personnel in separating the T/C support column, marking the I/S when taking them out, and placing them back in their original positions. | Mitsubishi Heavy Industries | 10-21 May 2004 | 10 |
| 3. Assembly and installation of the new CI | Train personnel in lowering down the new CI into the reactor vessel, performing alignment, measuring the clearances at the outlet nozzle and the crevice insert, and shrink fitting the radial support key. | Mitsubishi Heavy Industries | 12-23 July 2004 | 28 |

T/C: thermocouple; I/S: irradiation specimens

### 5.8 Summary

The work selection and planning phase of a scheduled outage, or of an in-service inspection campaign, is one of the most cost-effective periods for implementing work management. By judiciously selecting work (including those tasks that will not be performed), time, manpower, and dose can be saved. By effectively planning work before procedures are fixed and equipment has been purchased, changes can be affected easily and inexpensively.

The location of job planners can be optimised by centralising all appropriate workers (planners, engineers, schedulers, etc.), thus fostering and facilitating interdisciplinary communications. In addition, the proper scheduling of jobs to co-ordinate the use of services, scaffolding, installed shielding, water shielding in pipes and tanks, etc., and the use of scale models for planning purposes (as well as training and worker orientation) contribute to the efficient use of resources.

The key issues in the effective selection and planning of work include the use of realistic assumptions when deciding upon the necessity for performing work, the selection of only those jobs which are "necessary" to the safe and efficient running of the plant and the implementation of a tight but not rushed schedule to reduce the risk of rework. In terms of job planning, the effective incorporation of lessons learned from previous jobs, or from similar jobs performed elsewhere in the nuclear industry, is essential. This sharing of experience, through data bases and communication networks like ISOE, INPO, WANO, etc. can provide very useful experience and help to avoid "reinventing the wheel". By concentrating on those jobs which are the most dose intensive and by making effective use of available experience, work selection and planning activities will be optimally focused and directed.

# 6. WORK PREPARATION

*The success of work greatly depends on the quality of the preparation. To achieve good preparation, it is essential to understand the source term in order to select appropriate dose rate reduction techniques such as decontamination and shielding. Tools and equipment, such as robotics to avoid exposure, as well as improvements of the working environment are also effective. Since these techniques constantly develop and improve, it is important to choose the best available at any time.*

## 6.1 Introduction

Work preparation in the context of this report covers all activities considered or performed before and during a job in order to prepare the site and the work crew. A large amount of preparatory work must be done prior to the outage and all efforts to prepare and support the task and its working environment are essential if working conditions and radiological protection are to be optimised. Therefore, the work preparation should properly reflect the multi-disciplinary nature of the work to be performed.

In order to optimise radiological protection, factors affecting the source term, the duration of work and the number of workers exposed need to be addressed as part of the work preparation. This chapter focuses on the technical and operational aspects of this preparation, with particular focus on the source. Administrative aspects are discussed in Chapter 5.

## 6.2 Source term characterisation

In a nuclear power plant, the main sources of occupational exposure are the activated products arising from the structural material of the nuclear reactor. In order to develop appropriate exposure reduction measures for these sources, it is important to understand their characteristics. Source term characteristics include the nuclides and their spectrum, the amount of radioactivity present and its spatial distribution, the dose rate distribution, etc. Equipment needed to evaluate these characteristics must be calibrated and kept in a ready-state so that it is available and operational when required. The simulation of the dose rate distribution based on measured or estimated values is also useful for work optimisation.

***France: Source term characterisation***

EDF uses a CZT (Cd, Zn, Te) spectrometer to measure gamma spectra from point, surface or volume sources. Measurements are made systematically at each outage on specific circuits in order to:

- Characterise the contribution of each nuclide to the ambient dose rates.
- Obtain a diagnostic for the contamination of circuits.
- Ensure a follow-up of circuit contamination from one fuel cycle to the other.
- Identify as soon as possible the presence of potential “pollution” which could generate an over contamination of circuits.
- Involve RP officers and increase their awareness about contamination problem management.

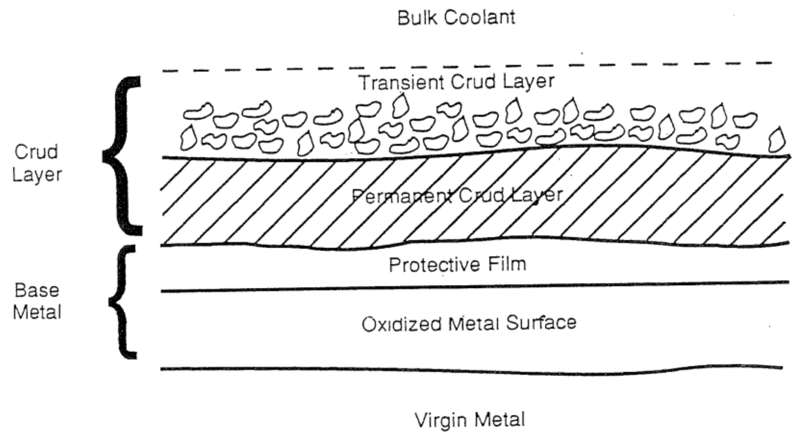
**_Spain: Combination gamma scanning techniques and 3D dose simulation in dose optimisation_**

For dose optimisation of work planned at the site, an estimation technique combining gamma scanning and 3-D dose simulation, developed under EU joint research, was applied at the Almaraz NPP. Dose rate maps of the area calculated in two planes using the VISIPLAN tool were in agreement within 20-30%, which is good considering the accuracy of the point-kernel calculation method used in VISIPLAN and the gamma scan calibration method proposed for the scan interpretation.

## 6.3 Source term reduction techniques

The radiation sources to which workers can be exposed may reside inside systems and piping, on surfaces and in air. The following section describes some of the techniques for reducing or removing these sources, thereby reducing dose rates to workers. In the case of crud removal, the objective of these various techniques is the removal of the transient crud layer by physical or chemical means with minimal disturbance of the protective film layer (Figure 5) in order to reduce in-plant dose fields.

Figure 5. **Reactor coolant system corrosion product deposits (CRUD) layer**




### *Chemical decontamination*

An effective method to reduce radiation dose is the removal of radioactive materials and metallic precursors by chemical decontamination of system internals. Chemical decontamination removes radioactive materials such as Co-60, which adheres to or becomes absorbed into the surface of devices or piping in the reactor coolant system, by dissolving it with a decontaminant. Chemical decontamination processes have been commercially available for nuclear plant application since the early 1980s.

The most common and effective types of chemical decontamination processes use oxidation and reduction reactions to remove radioactive material build-up from various component internals (i.e. piping, pumps, valves and tanks). Although more widely used in reactor recirculation (BWR), reactor water cleanup piping or running gears of main coolant pumps (PWR), there are also applications for these processes in PWR steam generator heads.

While many utilities today routinely perform chemical decontamination during refuelling outages, some find it necessary to perform large-scale maintenance operations before attempting decontamination. ALARA cost-benefit analyses are generally the basis for decisions on performing the process. Factors influencing these analyses are plant-specific dose rates, projected dose savings, the value of a man·Sv and the technical acceptance by the organisation.

### *Japan: Full system chemical decontamination*

A replacement of the weld-type reactor core shroud and other reactor internals was conducted at the Tokyo Electric Power Co. (TEPCO) Fukushima Daiichi NPS Unit 3 (BWR, 784MW) during its 16th periodic inspection from May 1997 to July 1998. In this replacement work, full system chemical decontamination (FSD) was performed.

Average decontamination factors of 43 at the RPV bottom and 46 at the reactor recirculation system (RRS) surface were obtained by FSD. The activity and metal removal were approximately 10 TBq and 72 kg, respectively, and the waste generated by the FSD was only 5.4 $m^3$ of ion exchange resins. After mechanical cleaning, the dose rates at the RPV bottom were 0.03 mSv/h under water and 0.2 mSv/h in air, with shielding in the RPV. Due to the decreased dose rate in the RPV, occupational exposure was 11.5 man·Sv (the target value was 12.6 man·Sv).

The collective dose was further reduced to 4.6 man·Sv during similar replacement work in Fukushima Daiichi NPS Unit 1 (BWR, 460MW) during the 22nd periodic inspection from December 2000 to September 2001.

### *Japan: T-OZON chemical decontamination procedure*

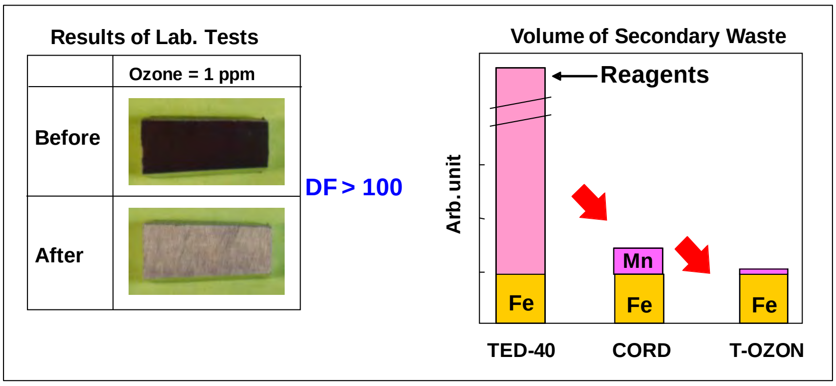
The principle of chemical decontamination is based on dissolution of metal oxides on materials. Dissolved metals, such as Fe and Cr, can be removed easily by an ion exchanger. Superior decontamination technology can achieve a high decontamination factor, minimum secondary waste, and no adverse impacts on material integrity. Based on these characteristics, the T-OZON decontamination process was developed in Japan. The principle of T-OZON process is as follows:

- Oxalic acid reduces ferrites to soluble Fe; ozone oxidizes chromites to soluble Cr.
- After the chemical reactions, both reagents can be easily decomposed.

In the T-OZON process, the secondary wastes of reagents are $O_2$, $CO_2$, and $H_2O$. The volume of secondary wastes can be decreased dramatically.

The main features of the T-OZON chemical decontamination process are:

- High decontamination factors.
- Minimum secondary waste volume.
- No adverse impacts on material integrity.




An example of the application of the T-OZON decontamination process was its use on the Hamaoka Unit 3 (BWR 1 100 MWe) primary system (primary loop recirculation piping-PLR; reactor water clean-up system-RWCU; residual heat removal system-RHR). With this process, average decontamination factors of 16 for stainless steel and 7 for carbon steel were obtained, and the dose rate in the drywell was reduced by half. This reduction corresponded to a decrease of 280 man·mSv of successive inspection work. One of the main features of the T-OZON process is minimum secondary waste volume, and wastes generated in this application were 2 $m^3$ of ion exchange resins and 0.4 $m^3$ of cartridge filters.

*United States: Chemical decontamination (Susquehanna NPP)*

Susquehanna Units 1 and 2 (BWR) achieved the lowest recorded recirculation piping contact dose rates of 15 mR/h after full system chemical decontamination and depleted zinc injection in 2004. Their dramatic source term reduction accomplishments were achieved through a series of plant management initiatives, including:

- Condensate filtration (June 1999).
- FW iron injection (July 1999).
- HWC (August 1999).
- Chemical decontamination (March 2001).
- GEZIP (DZO) (December 2002).
- Chemical decontamination (March 2001).

Susquehanna achieved US BWR industry low BRAC points dose rate level of 15-25 mR/h (on recirculation/riser piping). The lesson learned from this experience is that the Susquehanna achievement took strong commitment to source term reduction with a plant wide approach over a period of 5 years.

### *System flushes*

Flushing of systems and piping to remove radiation sources and hot spots can reduce dose rates in work areas by forcing radioactive material present inside piping to downstream areas where workers are not affected. Flushes may be performed through different routes, generally ending up in the waste-water handling system or reactor-water cleanup system. Keys aspects of an effective flushing programme include early identification of the source, procedure development, support of the operations department and assurance of a scheduled window. To optimise dose reduction, consideration should be given to the timing of flushes in relation to the work schedule. Often, the appropriate window is early in an outage if a unit is shutdown, which is particularly important for flushes which can only be performed while the reactor vessel head is still installed. In addition, system flushing with full system pressure and temperature, and with a maximum flow rate, is most effective.

Hydrolasing piping flushes remove radioactive materials that contribute to local area dose rates and either capture them by filtration or distribute them throughout the reactor vessel, out-of-core piping or tank internals. Hydrolasing utilises high pressure water (70-1 500 bar/1 000-20 000 psi) to force radioactive crud, silt or resin material from reactor pools, nozzle thermal sleeves, tank eductors and other dead leg or crud trap areas. The flushing of primary heat exchangers before maintenance or inspection work can also dramatically reduce dose rate and dose for the total job. High-pressure hydrolasing (800-1 000 bar) with special lances has also proved effective in preparing for the exchange of piping by reducing dose rates, thereby allowing reduced usage of personnel protective equipment.

Underwater vacuum cleaners are used when hydrolasing piping penetrations inside reactor vessels. Vacuums collect and filter radioactive particles forced out of tight areas by a hydrolaser lance and limit the impact on vessel water clarity (from resuspension of removed particulate material) and outage critical path time. It should also be noted that the installation of flushing connections, through which partial system flushes and/or decontaminations can be performed, can save doses if the connections are appropriately placed.

Drawbacks to flushing and hydrolasing are that most of the radioactive material is only temporarily removed if no filtration system is available, and when redistributed can contribute to higher dose rates for workers in other areas.

***Japan: Contamination control of the RPV for refuelling***

In order to remove the reactor vessel head of a BWR for refuelling, the RPV must be full of water. In the process of raising the water level, the main steam piping, relief valves and isolation valves may become contaminated if radioactive crud from the reactor water falls into the main steam piping. If this occurs, radiation levels will increase. To prevent this occurrence at Japanese BWRs, clean make-up water is injected into the main steam piping prior to filling the RPV with water for refuelling. The injected make-up water fills the main steam lines up to the level of their entry into the RPV, thus preventing contaminated reactor water from entering the main steam lines and possibly causing contamination. This will reduce dose rates in the vicinity of the main steam line valves (relief and isolation) and will allow work on these valves to be less encumbered by the use of personal protective clothing.

***Surface decontamination technology***

Several non-destructive mechanical decontamination techniques are available for removing both loosely or tightly adhering surface contamination, some of which are discussed here.

*High pressure water hydrolasing* technology is very effective at reducing loosely adhering contamination on surfaces of components, in tanks or refuelling pools. Pressures up to 250 bar (for manually operated) and up to 1 000 bar (for remotely handled) spray nozzles make this a very effective and low cost process.

*Abrasive blasting* technology uses glass or plastic beads to achieve high decontamination factors, effectively reducing dose rates at surfaces with oxide layers from primary water. However, because of its higher degree of abrasion, it is not suitable for sensitive surfaces. Some of the abrasive medium can be reused for as long as it is technically effective. An automatic separation process removes the contaminated waste fraction from the medium fraction.

*$CO_2$ cleaning* is a pneumatic dry process that uses dry ice as the decontamination medium. While similar to conventional abrasive blasting, it does not use hazardous or abrasive media, and can therefore be used on sensitive equipment such as electronics. On the other hand, the decontamination effect is lower for hard oxide layers. Although some form of ventilation is required for contamination control, the $CO_2$ cleaning process does not generate costly secondary wastes such as water or abrasive aggregate. The technology is mainly effective on softer materials like wood, rubber and plastics, or to remove paint or coatings.

*Ice blasting* is a wet process which uses small pellets of ice as the cleaning media. Ice blasting uses a refrigeration unit and ice grinder to produce ice chips which are delivered to contaminated surfaces with compressed air. Such systems can be used by robotics, and produce approximately 60-90 litres of water per hour. Inherent safety features of ice blasting include lower heat stress concerns, lower airborne levels from a wet environment and lower nozzle thrusts lessening operator fatigue. Disadvantages include slower decontamination rates as compared to conventional methods and high noise levels (typically 110 dB).

*Ultrasonic cleaning* is a physical decontamination treatment based on the use of ultrasonic waves in a water bath. The ultrasonic generator produces the ultrasound at a frequency between 10-100 kHz. A transducer converts this high frequency energy into low amplitude vibrations at the same frequency. Decontamination is accomplished through the formation and violent collapse of thousands of minute bubbles, which lift radionuclides from the object's surface.

*Ultrasonic fuel cleaning* is an effective means for removing PWR fuel deposits, hence mitigating the potential problem of axial offset anomaly (AOA) in PWR reactor cores. In addition the reduced fuel crud inventory has been shown to reduce dose rates on subsequent shutdown refuelling. Current ultrasonic fuel cleaning technology is also effective for exposure reduction because it removes deposits on the surface of fuel. In addition, ultrasonic fuel cleaning does not cause any additional radioactive wastes. While this technology was developed for PWRs, it is also thought to bring about the following advantages to BWRs:

- Mitigation of fuel issues associated with potential crud at plants with high iron levels.
- Reduction of Co-60 concentration in the reactor water resulting from the removal of its largest source, thereby reducing radiation fields and decreasing the required amount of depleted zinc.
- Reduced loading of noble metals on fuel following the injection of noble metals, increasing the relative proportion of noble metals on the surfaces of devices within the reactor.

***Japan: Decontamination by blasting***

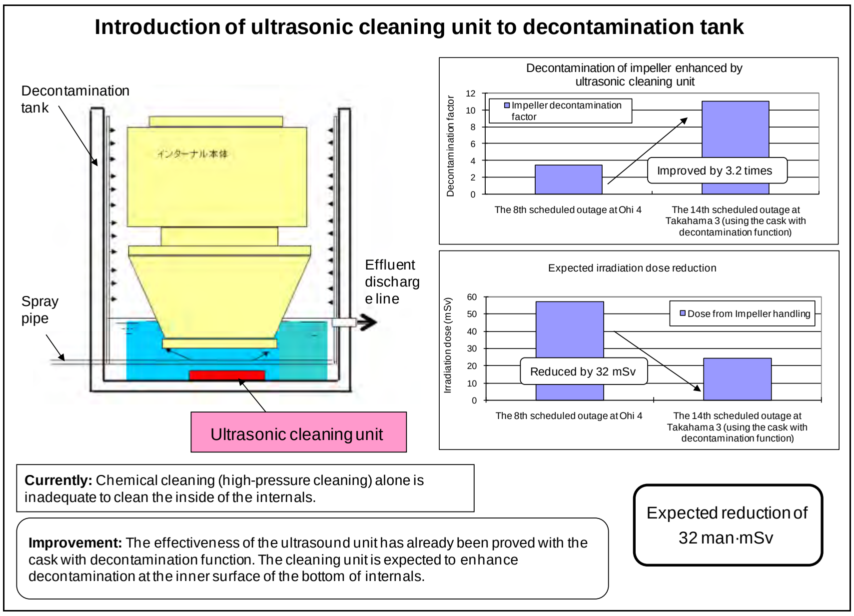
From the 1990s, advanced decontamination methods using blasting have been developed. One of the techniques used is the combination of cavitation jet (CJ) decontamination with blasting. Through an applicability test, it was found that the effectiveness of the combined decontamination process is higher than simply adding their individual effects. The table shows the results of the applicability test with actual equipment.

**Applicability test results of decontamination with CJ+blasting**

| | Before decontamination | After decontamination | Decontamination factor |
|---|---|---|---|
| Sample 1 | 40 mSv/h | 0.7 mSv/h | 166 |
| Sample 2 | 25 mSv/h | 0.63 mSv/h | 111 |

***Japan: Decontamination of the reactor coolant pump internals by using ultrasonic cleaning***

Chemical washing and high-pressure water have been used to decontaminate the RCP internals at the Ohi NPP. The ultrasonic cleaning unit, which has already been proved effective at another plant, is to be introduced for the decontamination tank to enhance decontamination in a cost-effective manner. This measure is expected to reduce the dose by 32 man·mSv. The schematic diagram is shown below.



***Romania: Cernavoda NPP decontamination technology***

Decontamination costs time and money, and potentially exposes workers to radiation doses as well as chemical and industrial safety hazards. Rather than developing complex technologies for decontamination, Cernavoda NPP created an efficient system based, firstly, on practical principles (improvement in the safety and health conditions for workers in the area by reducing or removing loose contamination) and also in the reduction of the amount of radioactive waste which is expensive to dispose. Operating experience has demonstrated that the maximum efficiency is obtained when decontaminations are made by very well trained personnel. The success of this decision consists of:

- The lowest dose and the best quality of the work.
- Minimum consumption of a decontamination agents, water and other consumables.

These goals were obtained using accurate knowledge (data) about origin (source) of contamination, and proper solutions (strategy) to decontaminate equipment, tools, and materials for reuse/recycling, obtaining the lowest quantity of secondary waste.

***United States: Ultrasonic cleaning fuel cleaning***

In the United States, ultrasonic fuel cleaning has been applied to such PWRs as the Callaway, South Texas and Vogtle nuclear power stations. At the Callaway Nuclear Power Station, a dose rate reduction on the order of 50% has been observed at plant shutdown after operation with the cleaned fuel installed.

### *Water chemistry control*

Water chemistry is an important factor to achieve chemistry regimes that favour continued reduction in source terms, including the prevention of crud adherence on the surfaces of devices and piping. This involves an optimisation of chemical conditions during power operation, as well as during transients, start-up and shutdown. While some plants prefer to follow their initial water chemistry specification, the following section describes several techniques that have been used successfully in some plants for source term reduction.

*Zinc injection*

Zinc injection is an effective method for reduction of dose rate, and has been successfully applied at a number of nuclear power plants worldwide to control the adhesion and accumulation of radionuclides in piping. This method is intended to control the corrosion rate of the primary piping and devices by increasing the Zn concentration of the reactor water through the injection of Zn ions inside the reactor. The injected Zn forms a fine film on the surface of the fuel cladding, piping and equipment. As a result, the release of cobalt from the fuel into the reactor water and the subsequent deposition on the surface of the piping and equipment are decreased. It is well known from operational experience that control of the corrosion rate will result in the control of the adhesion/accumulation rate of radionuclides to pipe surfaces and, consequently, control of the upward trend of the surface dose rate.

In BWRs in particular, the zinc injection method is also used to control the increase of the dose rate resulting from hydrogen injection applied as a countermeasure against inter-granular stress corrosion cracking (IGSCC). Zinc injection is often used in association with noble metals injection, which is implemented mostly in the United States. While natural zinc oxide (ZnO) was originally used for Zn injection, the dose reduction associated with controlling Co-60 is partially offset by the Zn-65 generated as an activation product of Zn-64. Consequently, there are cases where depleted zinc oxide (DZO), in which Zn-64 has been removed in advance by isotope separation, has been used.

*High lithium operation and application of enriched boron*

In PWRs, high pH operation can bring about exposure reduction effects. Recently in Japan for example, PWRs are operated at a high pH, with a target of 7.3 at 285°C. The pH is controlled by adding lithium as a pH adjuster. Because boron concentration is high at the beginning of the cycle, applicability of high lithium operation has been investigated as a means of pH optimisation through the entire operation cycle. Moreover, the application of enriched B-10 as a chemical shim control material has been studied with respect to decreasing boron concentration in reactor water.

*Optimisation of dissolved hydrogen concentration*

In PWRs, hydrogen is added to the primary coolant to prevent stress corrosion cracking (SCC) due to dissolved oxygen by inhibiting oxygen generation arising from radiolysis of the primary coolant. The chemical composition of crud is also considered controllable through appropriate control of the dissolved hydrogen concentration. Considering these two effects, a study on the optimisation of dissolved hydrogen concentration has been undertaken in the US and Japan with the objective of controlling SCC as well as reducing the dose rate.

*Ni/Fe control operation*

The control of iron concentration in reactor feed water is important from the perspective of reactor fuel integrity. It is also important from the perspective of exposure reduction and efforts to reduce iron concentration have included: the injection of oxygen to prevent the corrosion of the feed water system piping; the installation of condensate pre-filters to remove the iron contained in the condensate; and the improvement of the condensate demineraliser resin.

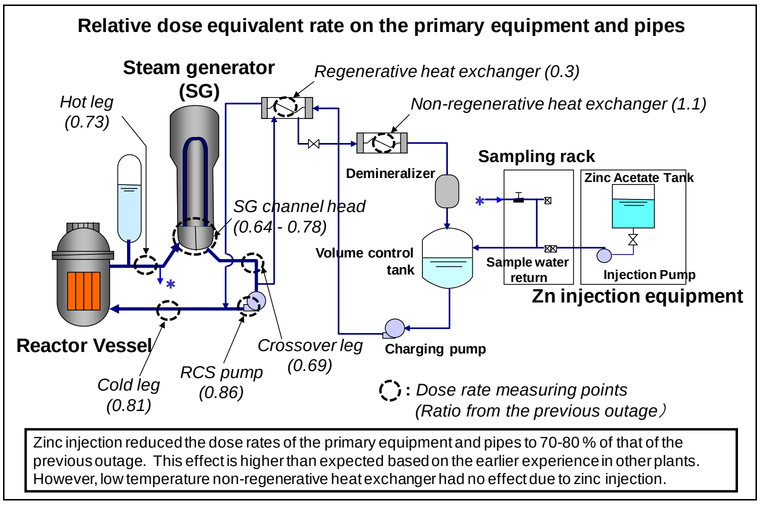
Based on the theory that it might be possible to immobilise radioactive cobalt generated from Ni and Co on the fuel rod surface by balancing the iron concentration proportionately with the Ni concentration in the reactor water, the Ni/Fe control method has been proposed. The Ni/FE control method aims to operate the plant such that the ratio of nickel to iron concentrations in the feed water is maintained at 0.2 or less. In general, Ni ions brought into the reactor will react with Fe crud on the surface of the core fuel cladding and generate nickel ferrite, which will then adhere to the surface of the cladding. As a result, other ions with chemical behaviours similar to Ni (e.g., Co, Co-60, and Co-58) will be incorporated as ferrite and immobilised on the reactor fuel surface, resulting in a lower concentration of the ion state radioactivity in the reactor water. This method was applied for the first time in Japan at Onagawa Unit 1 and Kashiwazaki Kariwa Unit 1 (BWRs), with significant performance. As a result, it has been employed in many of the new plants subsequently constructed in Japan.

*Ultra-low Fe/high Ni operation*

In some Japanese BWRs, the "ultra-low iron/high nickel operation" was developed for plants using a fuel type called "BJ fuel" (fuel which has a pure zirconium liner inside the high corrosion-resistant fuel cladding). This operation is a combination of two different concepts. One is the reduction in the amount of generated radioactivity by controlling to the maximum possible extent the iron crud quantity transferred from the feed water to the reactor water (0.1 ppb or lower of the feed water concentration) and thereby controlling the quantity of nickel ferrite and other crud to the surface of the core fuel. The other is the reduction in the adhesion or accumulation of radionuclides in reactor water to the outside of the reactor core by controlling the corrosion of the piping and devices outside the reactor core by maintaining the nickel ion concentration of the reactor water at the highest possible level. This operation has been applied to several plants including the Onagawa Nuclear Power Station and, as a result, its usefulness has been demonstrated.

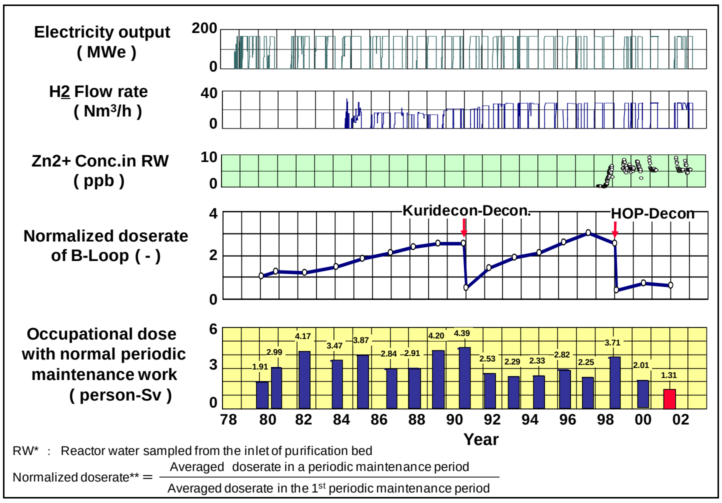
***Japan: Zinc injection (Tsuruga Unit 2 and Fugen)***

Zinc injection at the Tsuruga NPP Unit 2 was implemented to assess its effects on (1) water chemistry, (2) decreasing dose rates on primary equipment and piping, and (3) fuel performance. Zinc injection had been performed for eight months in the 14th cycle with zinc concentrations of 5-7 ppb in the primary coolant. Although the concentration of radioactive cobalt was increased by a factor of ten following zinc injection, the increase was within the expectation based on European experience. Additionally, the dose rates of the primary equipments and pipes (hot leg, cold leg and steam generator water room) were decreased by 20-30% compared with the rates measured during the previous refuelling outage.




At Fugen NPP, dose rate control technology combining system chemical decontamination and zinc injection was implemented as an exposure reduction measure during a periodic inspection. Fugen is a heavy-water-moderated boiling light water cooled, pressure tube type reactor, and is a prototype advanced thermal reactor. Fugen ended its operation in March 2005. The experience of the zinc injection at Fugen showed the following results:

- Zinc injection after decontamination effectively suppressed the re-adhesion of Co-60 on the surface of piping and maintained the radiation source at a low level.
- The occupational exposure dose in the 17th and final inspection period was at the minimum (1.31 man·Sv) throughout Fugen's operational period.
- Permanent and effective dose control measures for a plant were achieved by these water chemistry control technique developments and, in this way, effective exposure dose control measures were established.



***Reactor water clean-up***

A part of the primary coolant of the nuclear reactor is always extracted and cleaned up during operation in order to remove radioactive material in the coolant. Purification of the coolant is performed using ion exchange resins and particle filters. In PWRs, purification using the chemical and volume control system also is performed; in BWRs, the post-turbine condensate is cleaned up using condensate demineralisers.

***Ventilation and filtering of airborne contamination***

Ventilation, filter systems and temporary containments are effective at controlling airborne contamination. Properly designed and applied ventilation, which typically employs HEPA filtration, can preclude the need for respiratory protection for workers, especially for those working in the vicinity of the source area. Factors such as the placement of HEPA ventilation hoses and hoods, hood design, capacity and capture velocity must be considered when selecting a unit. The type of work to be performed also impacts the type of unit used. Grinding, for example, will require hoods with higher face velocities to capture materials. Specialised filter types (charcoal filters) must be used when iodine activity has to be considered. For effective operation of these filters, hazardous conditions that can destroy filter capability have to be avoided (high humidity, organic solvents).

***Shutdown operations***

Proper shutdown chemistry is necessary to ensure that primary system dose rates and contamination levels are maintained ALARA to the extent that shutdown operations influence these parameters.

*Addition of hydrogen peroxide*

The oxidation operation is a method to actively remove radioactive cobalt from the system by accelerating the dissolution of radioactive cobalt from the piping and increasing the flow rate in the clean-up system. In this process, when the primary system turns into an oxidizing environment, nickel, Co-58, etc, are rapidly dissolved and their concentrations in the coolant increase. However, their dissolution rates will decline later and the decrease in concentrations will be further accelerated by cleaning. With the objective of accelerating this decrease, full water oxidation operations can be performed. In PWRs, this is undertaken when water is discharged from the primary coolant system during plant shutdown. The primary system is turned into an oxidizing environment by adding hydrogen peroxide to the water before discharge from the primary coolant system. This method, applied at many power plants, is called the "External Surface Crud Removal Method" because it removes external surface oxides of metal materials, a source of external surface radioactive crud, without removing the protective coat (internal surface oxides).

***France: Shut-down procedures***

An EDF study on shut-down procedures and their potential impact on dose rate has shown that the main steps contributing to limitation of radioactive deposits in the primary circuit are the following:

- A constant decrease of temperature.
- A sufficient quantity of hydrogen peroxide (eau oxygénée) introduced in the primary circuit.
- The duration of the purification (at least 15 hours for a 900 MWe plant).

***Japan: Operation starting temperature in the RHR system***

In Japanese BWRs, a method has been applied to lower the operation starting temperature in the residual heat removal (RHR) system during plant shutdowns with the objective of decreasing the system's dose rate. This method exploits the dependence of the quantity of radioactive deposition to the RHR system piping on

***Japan: Operation starting temperature in the RHR system*** (Cont'd)

the reactor water temperature. An investigation at Kashiwazaki Kariwa Nuclear Power Station Unit 5 revealed that the quantity of radioactive deposition to the RHR system piping is generally constant when the operation starting temperature is in the range of approximately 120-150°C (the initial value), but decreases below 120°C. In addition, by lowering the operation starting temperature from 150°C to 105°C, the increase in dose rate due to deposition will be reduced to approximately one-quarter of the previous value.

***United States: Braidwood's "Alternate Shutdown" or "Low Inventory" methodology***

In an effort to reduce exposure to workers during outage evolutions, Braidwood Station has implemented an alternate method of shutting down its reactor that enables them to save exposure to their workers. This method was derived from conversations within the radiation protection department when past outage performances were reviewed and the possibility of isolating the steam generator, the pressuriser and the associated piping from the increased contamination and radiation levels that occur while performing a forced oxidation through addition of hydrogen peroxide (*i.e.* crud burst) was proposed.

This alternate shutdown method is executed at Braidwood through closure of loop isolation valves (LSIVs) prior to the forced oxidation. This results in the lower activity water during shutdown to remain in the steam generator and the pressuriser. This also results in a smaller volume of water to be cleaned up than with a normal shutdown. The alternate shutdown method also ultimately reduces exposure and increases the productivity of the plant personnel because of the shorter time required to clean up this volume (to at or below the EPRI guidelines) and the necessary restrictions applied to entry to affected areas during the cleanup phase.

The benefits from this methodology have been very noticeable in the reduction of dose rates in the plant. The plant has experienced a 30-50% reduction in dose rates in the areas of the steam generator, the pressuriser, the associated piping and the general areas impacted by these components. This method has been instrumental in reducing exposure to workers while performing work activities at Braidwood and has been implemented at other Exelon plants.

## 6.4 Exposure reduction techniques

In addition to the methods described above to remove or reduce the radioactive source term itself, exposures to workers can also be reduced by employing methods that take advantage of the principles of time, distance and shielding.

### *Temporary radiation shielding*

Use of temporary shielding, especially during refuelling and inspection outages, is one of the primary methods used to reduce job specific and general area radiation levels. Areas which use the highest quantities of temporary shielding include the BWR drywell and PWR steam generators and loop piping. Many plants install in excess of 25 tons of portable shielding during outage work on various piping such as for the reactor coolant, cleanup, recirculation (BWR) and the primary loop (PWR). Effective temporary shielding requires a flexible system of different shielding elements in order to obtain the best results under the local conditions. Often, it is important to save space because of narrow working areas and the need to give sufficient workspace to the worker. Typical examples of effective temporary shielding elements include:

- Lead wool or lead sheet blankets (Pb wrapped in polyethylene for ease of decontamination).
- Lead sheets (5-10 mm thick).
- Specialised lead/steel shielding elements, tailored for repetitive tasks.
- Tungsten: high density (19.25 g/cc vs 11.34 g/cc for Pb).
- Concrete bricks (with stainless steel liner).

- Water shields (plastic polymer/resin type containers).
- Lead-impregnated expanding foam.

Supporting devices for these elements include special quick connecting scaffolding equipment with shield support hangers, and hooks and belts for direct installation on piping or supports. Application of shielding depends on the desired dose rate reductions, plant configuration and allowable pipe loads for direct shielding.

Although lead blanket shielding, often supported by scaffold structures, still accounts for the majority of temporary shielding, other alternatives are available. Options for direct shielding include solid lead or steel rings which surround piping or casings of large valves. Water shields offer some possible dose savings over lead blankets/sheets in terms of installation and removal since the carboy containers are lightweight and allow remote filling and draining.

Several important aspects of a temporary shielding programme implemented during refuelling and inspection outages include work scope review, characterisation of the work area (layout and configuration), cost-benefit evaluations, engineering analysis and planning of shielding requirements. The availability of a wide range of shielding elements and a well-trained team with sufficient skill to find the optimal solution are needed for installation of the shielding elements in a short time. Generally, an engineering analysis should be undertaken to ensure approval of allowable weight loadings for support of temporary shielding on plant systems and piping. The summation of all outage temporary shielding packages should be tracked to assure that the total weight loading is below engineering restrictions for each system.

In some countries specialised contractors employing skilled craftsmen and technicians perform portable shielding operations using precise documentation of installation and dose rate values together with photo/visual documentation. These teams have developed optimised tools for temporary shielding installation using experience gained from performing the job during numerous outages, combined with radiation protection and other practical knowledge. Such professional shielding teams have saved some 5-10% of the yearly outage doses at several plants.

An optimal shielding programme should be supported by appropriate work scheduling (Chapter 5). Filling pipes with water, or draining them at a time when no work is being performed, is cost free and can eliminate the need to install significant quantities of portable shielding, reducing the collective dose associated with its installation. It should be noted, however, that water will not significantly reduce dose rates in piping of less than about 10 cm (4 inches).

An additional good practice used in plants with high dose rates is to create shielded waiting areas near highly frequented working areas. These "Radiation Shadow Areas" are designated for workers to wait during work interruptions, technical discussions etc. Typical installation areas are in the PWR/BWR containment or in/near the BWR drywell.

***Asian region: Temporary shielding***

In some Asian nuclear power stations, cost-benefit analyses of shielding installation must be completed first as an engineering support for dose reductions. Lead blankets, mobile lead walls, lead bricks, tungsten sheets and water boxes are often used based on specific needs of systems, components and work environments. Shielding supports are constructed as permanent devices, which facilitate the installation of lead blankets and minimise doses to installation workers. Temporary shielding and semi-permanent shielding are always set up for high radiation area activities to reduce collective dose. Specially designed tungsten lead blankets are often used during outages for high dose rate piping shielding in the hot area. Because the tungsten blanket is

***Asian region: Temporary shielding*** (Cont'd)

composed of certain amounts of tungsten and poly materials, it is flexible and can bend to cover hot piping. In order to reduce the level of higher radiation working areas, temporary lead shielding will be installed especially in period of refuelling outages at reactor coolant system primary associated piping and equipment. Movable and fixed type shielding have also been installed depending on the working environment in auxiliary buildings such as RHR and steam generator letdown rooms with high radiation piping.

***Belgium: Biological shielding during outages (Doel NPP)***

At Doel NPP, the personnel assigned to install biological shielding is extremely well qualified and trained. The company to which they belong has prepared, over a number of years, a standard programme for installing biological shielding at the start of a unit outage. Its operatives are also radiation protection workers and the only ones, apart from the radiation protection workers of the plant and the contractor organisations, authorised to make certain dose rate measurements. All the biological shielding is installed in the first two or three days of the outage. Only the radiation protection department is authorised to move biological shielding, or to modify the nearby signs (indicating hot points, zone classification, etc.)

Installation of biological shielding on a pipe enabling monitoring of a valve

"Bracelet" type protection on a pipe

***Canada: New shielding materials (Pickering B NGS)***

At Pickering B NGS, the application of new shielding materials is driven by the need for lighter, more effective radiation attenuating materials to augment traditional PVC lead bags. Latest attenuating materials include a homogenous mixture of 50-200 micron tungsten particles distributed in an elastic silicon matrix. This formulation can provide a ½ HVL @ 2.5 cm and enables the production of mouldable sections that provide flexibility in shielding radiation on irregular shapes.

***France : Optimising shielding installation***

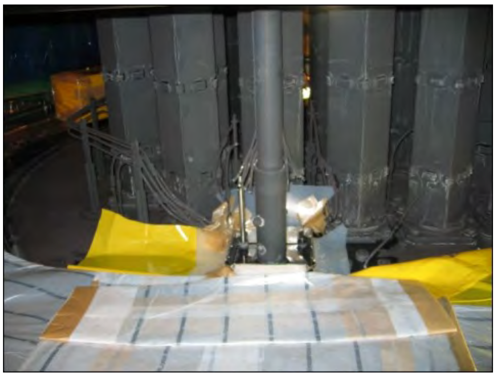
EDF has developed a methodology based on its PANTHERE dose rates modelling software to define the optimal scenario for shielding installation on primary loop circuits. This methodology has been applied on several 900 MWe plants. It appears that a dose saving of about 30% can be obtained on the works performed in these areas.

***Japan: Temporary shielding for RV core internals replacement (Ikata and Fukushima Daiichi NPS)***

Ikata Nuclear Power Station (Shikoku Electric Power Company) in Japan accomplished an RV core internals replacement (CIR) in a PWR for the first time in the world in 2004. The total dose received for the CIR was below 1/10 of the planned dose. There were two main reasons for this accomplishment: i) the dose equivalent rate from the old CI storage container was actually 1/3 of the design rate, and ii) various measures were implemented to reduce radiation exposure, including temporary shielding. Temporary shielding was installed at various places, such as the waiting area in the reactor cavity and surrounding the reactor vessel head. The temporary shielding for the RV core internal replacement is shown below.

At Fukushima Daiichi Unit No.3, a reactor internals (shroud) replacement was conducted for the first time in a Japanese BWR plant in 1998. Temporary shielding was applied in order to reduce total dose. The temporary shielding for the reactor internals replacement is shown below.

The temporary shielding
for the RV core internal replacement



Temporary shielding for replacement
for reactor internals (BWR)

***Switzerland: Lead shielding during outages (Beznau NPP)***

At Beznau plant, biological shielding was originally only installed in maintenance and monitoring areas, and the quantity of lead used was very small. At the start of the 1990s, it was shown that the dose received by the person installing the lead shielding was very low compared to the dose saved by installing this shielding for other operators. The quantity of biological shielding installed for the outage has thus considerably increased to about 120 tonnes in 1999 for replacement of the steam generator in Unit 2. Until the start of the 2000s, 80 tonnes of lead were used on average for each outage. A new policy was then developed: installation of biological shielding only in areas where work is carried out during the outage. This policy has led to a reduction in the quantity of lead used to about 40 tonnes per outage without increasing the collective dose of the maintenance works.

***United States: Temporary shielding for worker transit (Cook NPP)***

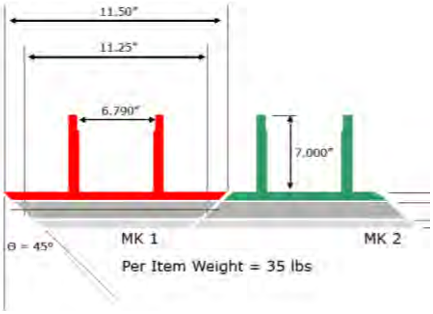
At American Electric Power's Cook NPP, several approaches to address the problems of temporary shielding installation have been used. For example, worker transit dose can be a significant problem. For the installation of temporary shielding in the lower containment, the shortest route for workers carrying shielding is through the lower containment airlock; however this path requires workers to pass through several elevated radiation fields. To eliminate this dose, shielding material is now transported from the upper containment hatch by use of cranes and floor hatches. Also, shielding of high transit pathways is performed early in the outage to save as much exposure as possible. The use of quickly installed and removed water shields has also been effectively employed, as has the use of permanent shielding hangers in areas where temporary shields are systematically used in each outage.

### *Permanent radiation shielding*

While temporary radiation shielding is often installed and works effectively in a refuelling outage, the one-time installation of permanent radiation shielding can be effective in situations where the overall exposure reduction to workers for a given job is small in comparison to a large exposure received during the shield installation, for example, in high dose rate areas and places with difficult access. When permanent radiation shielding is installed, it is necessary to consider conditions of stability and security of the shielding, including earthquake-proof safety. A partial movable permanent shield can also be effective in reducing doses while facilitating access through a hatch or other opening for inspection of piping and equipment.

***Canada: CANDU reactor face shielding (Pickering B NGS)***

A ReactorShield cap is a shielding device (square in shape) which is made of lead alloy (½” thick) sandwiched between 2 pieces of plastic. The four edges are bevelled to complement the adjacent pieces, creating an interlocking configuration. This configuration minimises the gaps between adjacent pieces once installed. ReactorShield caps have been demonstrated to provide excellent and consistent reduction of general radiation fields and streaming radiation emanating from the face. This shielding has been used with success during previous pressure tube replacement campaigns.




***Germany: Mobile shielding and permanent scaffolding (Philippsburg NPP)***

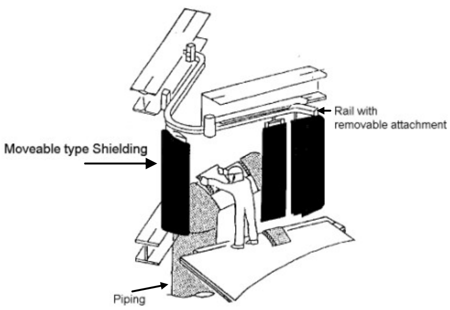
At Philippsburg NPP, a working group was established to investigate installed mobile shielding that has developed as a quasi “fixed installation”. This includes the transfer of mobile installations, if necessary for a long time protection of workers, to adequate installations proofed for stability and adequate safety against earthquake induced interference with safety-systems.

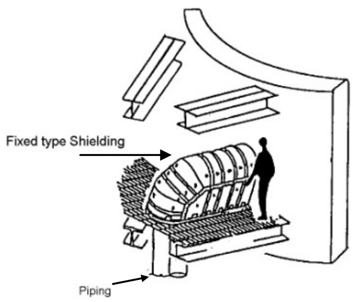
During an outage in areas with permanent high dose rates, permanent scaffolds are needed for maintenance work. These scaffolds can, if inspected and certified be installed on a permanent basis considering the stability and possible conditions under earthquake criteria. This way a collective dose reduction of approximately 2-3 mSv can be achieved each time the scaffold is installed and dismantled.

***Japan: Movable permanent shielding***

In some Japanese BWRs “movable permanent” shielding has been installed to decrease installation and removal times and corresponding worker exposures during maintenance work. Work-time reduction factors from 10 to 20, and dose rate reductions of up to 20% have been observed as compared with the use of conventional shielding systems (lead sheets and blankets).

Movable permanent shielding has been designed for easy access to piping and equipment to be inspected. Movable lead blankets are hung from permanently installed beams and rails of earthquake-proof design. Blankets are hung side-by-side and restrained from swinging by the use of bottom fixtures, and can thus be left in place during plant operation. By detaching the blankets from the bottom fixtures, they can be slid along their rails sufficiently far to allow easy access to the work space, but still provide some shielding value. There is no need for a lay-down space for removed shielding (none is removed), and the blankets are compactly arranged to allow sufficient working space. The figure shows a work space shielded by conventional shields and by permanent movable shields.

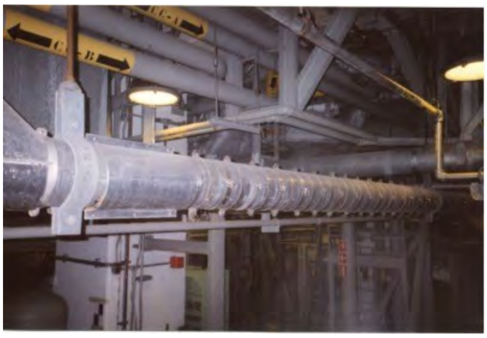


***Spain: Use of shielding (Almaraz and Cofrentes NPP)***

The Almaraz NPP (PWR) is equipped with large amounts of fixed biological shielding (25 tonnes). Fixed biological shielding is also installed around piping and valves that contribute significantly to the ambient dose rate. Some of this shielding is equipped with access hatches to enable opening or checking of valves. As a consequence, minimal biological shielding (around 6 tonnes) is installed during unit outages.

**Permanent lead shielding on a pipe in the Almaraz nuclear auxiliaries building**



**Fixed biological shielding with an access hatch for checking a valve at Almaraz NPP**

A re-design was also implemented to minimise, as much as possible, gamma ray and neutron flux in a cavity inside the containment building. The objective was to fill a cavity placed in the wall between the reactor coolant drain tank (RCDT) and the INCORE instrumentation tunnel. The cavity, closed with a metallic plate ready to be opened at pressures over 2 psi (LOCA design-basis conditions), was no longer necessary because of the application of the “leak before break” methodology. The cavity was filled with concrete blocks fastened with metallic sheets. This design change was executed during the 13th outage of Almaraz II NPP in 2001 and the 15th outage of Almaraz I NPP in 2002. Internal/external doses received during the development of the work were negligible. During power operation, maintenance of the reactor coolant drain pump usually lead to individual and collective doses that, following the design change, have been considerably reduced. Radiation levels before and after the practice are listed in the table below.

| Operation mode | Radiation level in contact with the cavity (mSv/h) | | | |
|---|---|---|---|---|
| | Gamma ray | | Neutron radiation | |
| | Before DC* | After DC | Before DC | After DC |
| Refuelling (thimbles withdrawn) | 10.0 | 0.06 | - | - |
| Power | 26.0 | 0.10 | 48.0 | 0.025 |

*DC: design change

At Cofrentes NPP (BWR), up to 80% of the triennial doses inside the drywell comes from the recirculation system and the clean-up system. Permanent shielding was installed in pass-by and stay areas, leading to reductions of over 50% of the historical trend. Its installation was less risky and had less radiological impact for workers in comparison with temporary shielding. Permanent shielding was made of lead blankets covered with non-flammable canvas and fixed to auxiliary structures.

| Dose rate before shielding (mSv/h) | Dose rate after shielding (mSv/h) |
|---|---|
| 0.7 | 0.42 |
| 2.86 | 0.36 |
| 1.1 | 0.3 |

### *Transfer of work away from sources*

In addition to dose reductions that can be achieved by reducing the physical source term or through the use of shielding, reductions can be achieved in some cases by increasing the distance between the worker and the source of exposure. Some approaches that can be considered include the prefabrication/pre-assembly of equipment or parts outside of the job site or the removal of in-plant components to low dose rate staging areas or machine shops for maintenance. Planners as well as design engineers and maintenance technicians are responsible for identifying components which can be fabricated in machine or electrical shops outside of radiation zones prior to installation. This technique has been used successfully, for instance, for prefabrication of pipe spools, flange welds, pipe struts and electrical wiring for valve actuators. If properly planned, a high percentage of welding can be done outside the radiation zone without stress from uncomfortable conditions and radiation exposure. In addition to saving dose, there will be improved quality and less rework.

Another useful technique is the removal of components from higher to lower dose rate areas for maintenance. Good examples include removal of valve actuators for service, valve disks for machining and pump motors or pumps for inspection. Equipment can simply be moved to a nearby low dose rate area, or to an on-site hot-shop for maintenance work.

## 6.5 Tools and equipment

### *Hot workshop and decontamination workshop*

To maintain plant component internals, spare parts and tools which become contaminated in the controlled area, a hot workshop is necessary. Workshop capacity within the controlled area avoids the need for the decontamination and release of parts to the cold workshop for maintenance work. A well equipped hot workshop of the same quality as the cold workshop may improve maintenance quality and save time and cost. Specialised equipment will enable maintenance even of complicated components.

Special decontamination workshops are sometimes integrated in the plant design of both PWRs and BWRs. These facilities, placed close to the hot workshop, are designated for all components or internals that are movable (perhaps after dismounting) as well as for tools. These facilities have proven to be very effective at reducing both dose rates and contamination to levels which are easy to handle in the hot workshop or at the working area, thus reducing exposure during maintenance work. Locating the hot workshop and decontamination workshop in the same vicinity will also facilitate maintenance work and reduce worker doses. A wide range of equipment that cannot be operated at the working area is available for decontamination, including:

- Decontamination chambers for larger components.
- Decontamination boxes for smaller parts.
- Baths of different size, equipped for ultrasonic cleaning, and also used for (electro-) chemical decontamination.
- High pressure water jet systems (130-250 bar) for use in the decontamination chamber/box.
- Blasting systems for glass, steel beads, etc., for use in the decontamination chamber/box.

### *Specialised tooling*

Proper tools are essential to workers in the field for maintaining doses ALARA, and the planning process and final work plan should ensure that the work crew obtains all appropriate tools for the job. Tool availability, control and house-keeping procedures should prevent problems due to inadequate tool supply or to leaving tools in radiation areas which requires cleanup by support crews and results in additional dose. The important aspect of tooling with respect to engineering controls involves identification, procurement or development and training in the use of specialised tools.

Examples of specialised tools which help reduce dose are automated/remote cutting, grinding and welding machines, remote in-service inspection (ISI) devices or snubber alignment/lifting tools. Many types of such specialised tooling are in common use, and their proper selection can also reduce time and dose. Air arc cutting is generally faster than oxy-acetylene torch cutting. Small tools like mirrors on reach rods can make inspections in awkward areas less difficult. Other tools used for easier access include electric lift trucks, ladders which reduce the dose from building scaffolding and video cameras on long reach rods for visual inspections in overhead areas. Usually, three main types of specialised tools can be considered:

- Holders for control and maintenance: a "holder" is a flexible system on which several different tools can be installed for use in multiple interventions (e.g.: the same holder can be used in the steam generator channel head for eddy current testing, plugging, etc).
- Maintenance tools: these can be used only for one type of intervention (e.g.: opening and closing the reactor vessel head studs).
- Tools developed for camera-assisted inspections or non-destructive exams (e.g.: "RITMIC" manipulator developed for implementing eddy current testing in channel heads).

On some occasions, for repair, inspection and exchange work, highly specialised and sophisticated tools have been developed. To test such tools, mock-ups have been used to assure proper functioning as well as personnel familiarisation. Both of these aspects help to avoid mishaps on the critical path and to save dose.

***Canada: Real time tritium and routine survey data displays***

As part of its regulatory requirements, certain levels of radiological hazards must be posted in a durable and clear manner. Traditionally, large dry-erase boards were used as the display medium. Today, Ontario Power Generation employs common internet protocol (IP) technology and a system of electronic LCD panels with low cost computers, or "bricks", as IP engines. The relevant survey technician's unit results, along with continuous remote area radiation monitors (RARMs), which include tritium level data, are displayed at all unit air locks, in real time.

***Japan: Specialised cleaner with brushes and high pressure jet nozzles***

In Japanese BWRs, the cleaning of condensate demineralisers involves several hundreds of elements, each of which require cleaning with a hand brush by contract workers using full-face masks and plastic suits. This task used to take four workers up to seven days for two demineraliser resin tanks. As a result of this time and exposure, a special cleaner with brushes and high pressure water jet nozzles enclosed in a small ventilated box was developed and applied at Tokyo Electric Power Company's Fukushima Daiichi site. The time required for cleaning the elements has been shortened by a factor of five, and respirators and plastic (upper) suits are no longer required. The physical burden of workers and the negative image of the cleaning work have been dramatically improved.

| | Hand brush | Cleaner box |
|---|---|---|
| Time to clean 432 condenser elements | 127 hrs | 26 hrs |
| Number of plastic suits and respirators required | 56 | 0 |

***Robotics***

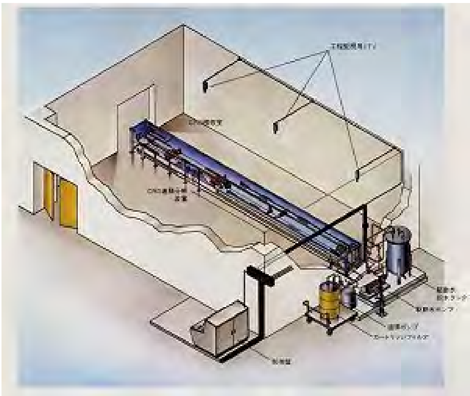
Mobile robots and remote handling devices developed for the nuclear industry have found cost-effective uses in the areas of radioactive waste handling, underwater inspections, equipment decontamination, surveillance in high radiation areas and radiation surveys. Often, remote handling is the only solution for repair work in high radiation areas such as the reactor interior. For intervention after severe accidents, robots are available which can negotiate stairs, perform underwater diving activities, and carry lighting, camera and radiation detection equipment. Small tasks can even be performed such as material/equipment retrieval. On the other hand, there are opportunities to develop more sophisticated industrial robots for application in high radiation hazard areas such as the decontamination of components or piping after replacement.

***Japan: Robots at NPPs of Tokyo Electric Power Company and Kyushu Electric Power Company***

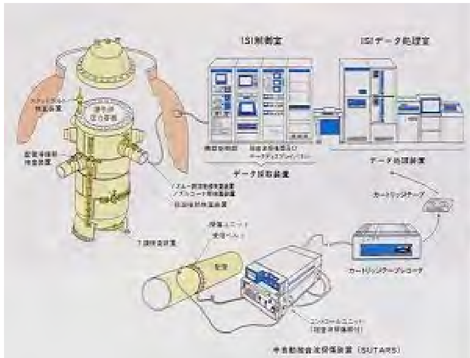
The following robotics technologies are being used by Tokyo Electric Power Company:

- Fuel handling machine.
- Control rod drive automatic disassembler (remote disassembling and cleaning of CRD).
- CRD handling machine.
- Reactor vessel ultrasonic inspection device.
- Reactor vessel head bolt tightening device.
- Remote operating vehicle.

**CRD automatic disassembler**



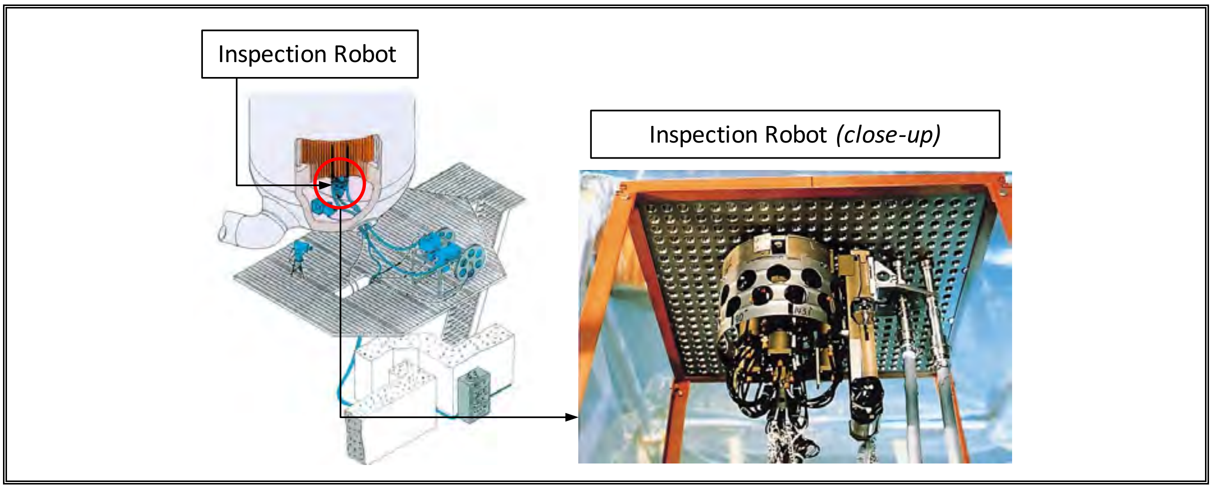
**Reactor vessel ultrasonic inspection device**



**Reactor vessel head bolt tightening device**

**Remote operating vehicle**

At the nuclear power plant of Kyushu Electric Power Company, robotics are used for eddy current testing of the steam generator tube




## 6.6 Personal protective equipment

The control of contamination is one of the fundamental ways to reduce the radiological risk to workers. Maintaining radiologically clean plant areas reduces protective clothing and respiratory protection requirements, which can in turn increase productivity. When productivity is improved, time and dose are saved. It is widely accepted that protective clothing diminishes dexterity, comfort and mobility and may add a heat stress factor for the worker. Respiratory protection devices (i.e. full face, bubble hoods, bubble suits) both impair vision and interfere with verbal communication.

It is therefore important to maintain a working environment where protective clothing and respiratory protection are not necessary. However, when the use of personal protective equipment is unavoidable, their selection should consider the nature of the radiological hazard, the work to be performed and the impact on work efficiency.

## 6.7 Work site optimisation and job co-ordination

One global subject in work preparation is the optimisation of the working area to improve working conditions (see also Chapter 5). Work must be scheduled and prepared with knowledge of all operations planned in the same area. This is especially important for the optimised use of all supporting activities and equipment. For example, the removal of large amounts of radioactive waste, especially high dose rate/activity waste produced during maintenance operations, has to be appropriately prepared and scheduled in order to help to maintain low dose rates at work locations. The removal of insulation material from larger piping should be planned and scheduled together with the insulation work. For extremely high dose rate parts (i.e. from reactor vessel interior) shielded intermediate storage must be prepared as part of the planning process.

The direct impact of factors such as the general organisation of tasks or the preparation of work is more difficult to quantify. Nevertheless, their importance has been underscored by the analysis of routine maintenance and post-incident operations. Analysis has shown that on average 20-30% of the collective dose associated with these operations could be due to mishaps or poor working conditions (Schieber, 1994). A quantification of such factors is essential for optimisation studies of radiation protection actions. These studies can be used not only for evaluating dose savings but also for calculating cost savings, as the reduction of exposed time sometimes implies a reduction of the operating costs associated with the work.

Even if there is good planning, there is still a need for someone in the work area to ensure that the work is well co-ordinated. Such area co-ordinators should report work status to the outage control centre. Outage managers have been effective in assuring continuous monitoring and field-coaching of the critical path work scope. Dose accountability at the work foreman level is important to ensure buy-in to dose budgets established at the task level.

The result of aggressive work process controls is, in part, the acceptance by plant personnel that radiation exposure is a "quality issue". The accumulation of unnecessary dose will be tracked and followed-up by supervisors to assure re-occurrence is avoided.

***Romania: Fuel channel inspection***

Following the development of the work plan, a "Radiation Protection Plan during fuel channel inspection" was elaborated. Before the start of the specific activity, many exercises were performed in special areas simulating the specific conditions on the reactor face. Nominated persons from the following departments were involved: fuel handling; maintenance; electrical; radiation protection; and AECL personnel. The work was performed continuously: during the day shift, inspections of the fuel channels were performed, and during the night shift, preparatory activities were carried out for channels to be inspected the next day. Because of the radiological protection measures and work practices implemented, there was no internal contamination of personnel nor spreading of free contamination outside of the Rubber Area/Rubber Change Area.

## 6.8 Summary

It is crucial to optimise the work site from the perspective of source term and exposure reduction and work efficiency improvement. One of the elements of this reduction is the dose rate in the working area. Source term removal, reduction by shielding or continuous control are effective for achieving dose rate reductions. Various tools and equipment that support work implementation are also appropriate. It is important to take advantage of these techniques as part of work preparation since many effective methods have been developed and a great deal of experience has been accumulated. Finally, support tasks such as optimisation of the work schedule and job co-ordination in the work area are also key components of work preparation.

# 7. WORK IMPLEMENTATION

*During work implementation, it is essential to ensure an efficient control of radiation protection "in the field". This includes organisational aspects such as the presence of radiation protection personnel and specific procedures, as well as technical aspects, such as the use of remote monitoring, access control systems, etc. The purpose of these controls is notably to check that what has been planned for ensuring occupational radiation protection has been properly implemented, to identify and implement corrective actions if necessary, and to initiate the collection of feedback experience.*

## 7.1 Introduction

The work implementation phase refers to the actual performance of the work and to those actions taken during this time which affect or facilitate the work. There are several areas where work management can effectively contribute to lowering dose as well as time and cost. Efficient work process control will help to assure that the objectives set during the work planning phase are met. The reduction of transit exposure and unnecessary dose will be facilitated by providing workers with sufficient radiological, plant and job specific information. Finally, the collection of feedback information will assist in real-time work management and facilitate the preparation of future work.

## 7.2 Work process control: division of responsibilities

Work process controls (see Section 5.4) are critical to the success of well planned outages. As many people will be involved in these controls, it is important to clearly establish the responsibilities of each as well as to create a flexible organisation to co-ordinate work and to resolve any problems encountered. Interdisciplinary communication is an essential component.

***Task managers/job supervisors***

Task Managers or Job Supervisors play an important role because they are in direct contact with the workers performing the jobs. To effectively control work, task supervisors must spend sufficient time at the work sites to be aware of progress and problems. It is also necessary to favour a close collaboration between supervisors and radiation protection personnel during the outage. The job foremen, often a contractor, must be able to identify and work closely with the job supervisor who is responsible for collecting information concerning the work progress and any problems encountered. To resolve such problems, inter-service communications must be quick and efficient. For this purpose, it is also useful to identify the persons who will co-ordinate information and report to the outage structure. Dose accountability at the work foreman level is important to the full acceptance of responsibility for task-level dose budgets.

The daily outage meeting must be the place where identified problems are solved in "real time", and where the planning of "unscheduled" emergent jobs and communication of unplanned work are elaborated in the same way as planned jobs (see Chapter 5). It is important that task supervisors, radiation protection staff and the people in charge of preparation and scheduling attend this meeting. It is also important during this meeting to inform the outage management structure of the actual outage dose evolution and to compare this with the projected dose. When specific problems are encountered, the participation of contractors should be considered, if appropriate.

***France: Pre-job meetings***

At EDF, two meetings grouping representatives from the contractors and utility staff (health physicists, job foreman etc.) are systematically organised to identify the job specificities and the logistic needs: a first meeting approximately one month before the work, and a second meeting the day before the work. EDF has also experimented during some of its units' refuelling outages with the use of a full time reactor building co-ordinator, who is the central contact point for any problems encountered, such as lack of electric current, problems with elevators, questions about permits etc.

***United States: Make-it-happen managers***

US nuclear power plants typically use "Make-it-happen" managers to assure continuous monitoring and field-coaching of the critical path work. Assigned the responsibility for a particular job (or jobs), these managers assure that obstacles encountered during the task are overcome. These can include such problems as a lack of institutional support (scaffolding, insulation or shielding groups, polar crane use, maintenance and electrical groups etc.), procedural problems encountered during the course of the work, or unplanned "emergent" work discovered during maintenance activities (broken/leaky valve, faulty pump etc.) In each case, the "Make-it-happen" manager is responsible for co-ordinating, in a multi-disciplinary fashion, the response to these problems such that the work is not adversely affected in terms of time, cost, or dose.

In BWRs, up to 65% of the total outage dose is received from work activities in the drywell. In the United States, the assignment of Drywell Work Co-ordinators and Managers, whose sole purpose is work process control and monitoring, has reduced work duration and dose in this critical plant location.

***Radiation protection personnel***

While the specific roles of radiation protection personnel, as well as the degree of radiation protection responsibility assigned to workers, may vary from country to country, their key function is to provide radiation protection assistance and advice to workers. Workers must therefore be able to identify the RP technician who will follow their job. This identification will of course be made if the workers receive a radiation work permit from the RP group. It is also possible to designate a particular RP technician for the surveillance of one type of job. RP personnel also have a key duty to provide timely and effective information to plant management to enable the managers to actively execute their duties in ensuring that doses remain ALARA and that radioactive materials are suitably controlled.

To ensure that regular radiation protection inspections are performed, especially during work which will modify the radiological environment, "radiation protection hold points" must be included within work procedures. The aim of these points is to "force" the workers to stop the job until the radiological conditions have been checked by an RP technician, or to verify that specific radiation protection actions have been implemented (e.g. installation of shielding, updating dose rates and contamination mapping etc.) In many plants, it is the expectation that the radiation protection manager or representatives have the authority to stop work activities in the field if the following conditions are observed:

- Change in the radiation condition.
- Unauthorised removal of temporary shielding.
- Non-productive work activities due to inadequate planning.

## 7.3 Access control systems

***Radiation work permits and controlled zones***

Radiation work permits (RWP) elaborated during the preparation phase (see Section 5.4) should be given to the workers by the RP staff. As the permits usually include prediction of dose as well as radiological conditions (dose rates, contamination levels etc.), they should be modified if the actual plant conditions differ from the planned ones. RWPs can include appropriate "stop criteria" for work (e.g. if there is modification of radiological conditions during the work or major mishaps etc.) which oblige workers to contact the RP staff if such criteria are encountered. A link between the electronic dosimetry system and the RWP identifiers is preferable in order to directly collect the individual dose and collective exposure associated with the job(s) for which the RWP was issued.

The control of access to, and time spent in, the controlled zone, particularly that part where workers are exposed to radiation, is important in reducing doses. An "electronic" control at the entrance to the controlled zone can be implemented using the RWP, allowing workers access to the controlled area only if the RWP is planned for the day considered. Sometimes, however, this system may not be sufficient to control access, for example if the period allocated is very long. Therefore, it can be useful to designate a person who will be in charge of controlling access.

***Electronic dosimetry systems***

Electronic and pocket alarming dosimeters allow dose monitoring and tracking of jobs on a real-time basis when used with real-time dosimetry hardware and software systems. These systems provide dose rate, total dose and stay time alarm levels with a high level of data integrity and retrievability (i.e. data can be retrieved even after a dosimeter has been damaged). To help prevent unplanned high exposures, it can be useful to set individual dose restrictions and to check worker doses upon entrance to and exit from radiological controlled areas (RCA). Automatic updates of worker doses when exiting the area and signing out on real-time dosimetry reader stations eliminates errors associated with reading analogue scales on self-reading dosimeters or pocket ion chambers, or from data entry errors of RWP dose data. This allows a better correlation between electronic dosimeters and official dosimetry of record (typically TLDs or film badges). Some plants are currently pursuing changes to their radiation monitoring programme to allow the use of electronic dosimeters as the dose of record.

Electronic dosimetry alarms can be set either in terms of dose rate or individual dose. Usually, when workers enter the task code, the alarm thresholds are immediately set up. The threshold should be low enough to prevent incidental exposures, while high enough to allow the job to be performed according to the specific radiological conditions. Workers should be trained to the actions to be undertaken when an alarm occurs (secure work, go to low level radiation area, call for RP assistance, etc.) Attention should be paid to the correct positioning of dosimeters, i.e. outside clothing so that alarms are visible and audible.

Electronic dosimetry combined with an electronic access control system can provide a form of access control into the RCA or local work locations, confirming radiation protection education, training and respirator qualifications as well as providing up-to-the-minute cumulative dose for each worker. Access control systems, in combination with a RWP system, can also prevent unauthorised personnel from entering controlled areas. The same may be done for local restrictions to separated areas (i.e. refuelling floor). These systems are also useful for job/area related dose recording and follow up.

***High radiation area controls***

The rules governing access to high radiation areas should be clearly defined. Usually, such areas are locked by different keys belonging to different work group supervisors (RP supervisor, operating chief supervisor, plant director etc.) In order to access such areas, workers should have received the agreement of all these supervisors, as well as a pre-job briefing explaining the specific risks associated with this area, the necessary protection rules and any information useful for their security and radiation protection.

***Belgium: Badge in and out systems (Doel NPP)***

At Doel NPP, "Badge in and out" systems are used at the entrance of the controlled area and also at each level of the reactor building or for some specific jobs (steam generators, primary pumps etc.).

***Belgium, Sweden, Slovenia, United Kingdom: Alarm levels on electronic dosimeters***

In Belgium, at Doel NPP, standard alarms on electronic dosimeter are set at 0.25 mSv and 1 mSv/h per entrance in the controlled area. These alarms can be changed for particular jobs. In that case, a sub-controlled area is activated.

In Slovenia, at Krško NPP, the electronic dosimetry database is connected to the plant personal database and radiation work permit database. The alarm levels are also controlled with respect to issuing more radiation work permits than planned.

In Sweden, at Ringhals NPP, the standard alarm on an electronic dosimeter is set at 1 mSv per entrance, which can be modified by RP staff as appropriate. For example, in case of a high dose rate, the alarm is set at a higher value with the agreement of the job supervisor. It is also possible to set a dose rate alarm. At Forsmark NPP the standard alarm level on the electronic dosimetry system is set at 0.5 mSv per entrance. The RP supervisors can change this level. Another standard alarm level is 10 mSv/h for dose rate. There is also an annual alarm level of 18 mSv which is administrated via the local dose register database (LDIS). Other alarm levels, or action levels, may also be set by the RP staff if needed. For pregnant women there are special dose limits, and the dose for the foetus must not exceed 1 mSv during the pregnancy. In case of pregnancy, the woman has the right to be relocated to the uncontrolled area but in case she wants to continue working in the RCA, the alarm limit is normally set at 0.1 mSv per entrance. The limit is administrated via LDIS and is always discussed with the woman herself, the RP supervisor and the woman´s work supervisor.

In the United Kingdom, electronic dosimeter dose and dose rate alarm levels are specified on the RWP, but it is a worker entering a task code on the EPD access control terminal that actually programmes the alarm levels. Typical alarm thresholds are 200 µSv and 500 µSv/h for most general, low risk activities and 500 µSv and 5 mSv/h for specific, higher risk tasks (for example valve work).

***France: EDF red zone access procedure***

Red zones are high radiation areas that are closed with two independent padlocks. One key is in possession of the radiation protection service, and the other one is owned by the Direction. Both are kept in a specific chest with restricted access. The access authorisation is given by the radiation protection director of the NPP, after a pre-job briefing. This briefing is performed in presence of the workers, the foreman, a member of the Risk Prevention Service, and the "Operating chief", and includes:

- The examination of the different tasks/steps of the intervention and the identification of the workers who will carry out these tasks.
- The review of risks and the examination of unfavourable scenarios.
- The validation of the provisional dosimetry for each worker.
- The validation that the operating state of the plant allows the intervention.
- The validation of the workers list, their provisional dosimetry, the intervention area, and the duration of the activity through a form signed by the workers' management, the Risk Prevention Service, the operating chief, and the Director.

***Germany: Concept for the use of official electronic personal dosimeter in Germany***

The Electronic Personal Dosimeter (EPD) contributes to better exposure control and the development of a sound radiation protection culture due to direct feedback of dose information. Currently the use of EPDs in Germany is limited to operational dosimetry. Typically EPDs are used in addition to the official passive dose meters in large nuclear installations and facilities like nuclear power plants, nuclear fuel cycle facilities, large research centres and in large hospitals.

Emphasis in the concept for the use of an official dosimetric system in Germany is given to the overall composition of those components which are necessary to measure the effective dose, to read out the measured data from the dosimeter, to transfer the data to a competent evaluating organisation and to deduce the effective dose from the measured data. The pool concept with access control is expected to be the typical concept used in nuclear power plants.

***Germany: Portal monitors (Philippsburg NPP)***

Portal monitors (friskers), which are able to measure simultaneously beta and gamma contamination, are used at the exit of the radiation protection area in Philippsburg NPP. The total body surface including hands, head and feet is measured by 14 beta gas flow proportional counters. Directly behind the beta counters, two large additional gamma plastic-scintillation detectors are positioned in the breast area (left and right side). As they are only sensitive to gamma radiation, they are able to detect incorporated gamma activity if present. The detection limit is about 1000 Bq (against Co-60, 3 sigma error) for a measurement time of 10 seconds. In this way, if some internal contamination exists, the worker is immediately sent for whole body counting and the dose assessment is much more accurate.

***Romania: Personal alarming dosimeters for dose accounting for specific jobs and access control***

The access control system at Cernavoda NPP Unit 1 has been designed to prevent any inadvertent/unauthorised access to areas where high radiological hazards are or may be present. "Controlled" zones, for which a special protection measure is required in order to control normal exposures, prevent the spreading of contamination and prevent or eliminate potential exposures, have been assigned as follows:

- Zone 3: no radioactive sources; no detectable contamination; dose rate < 0.0005 mSv/h.
- Zone 2: no radioactive sources; there is no contamination but it can occur due to the movement of personnel and equipments; no radioactive systems; dose rate is lower than 0.01 mSv/h; there are procedures for controlling the access from other radiological zones.
- Zone 1: contains radioactive systems and equipments as potential sources for contamination and/or significant radiation exposures; areas that are frequently accessed do not contain loose contamination.

Each access point to a room or clearly defined area where total radiation hazards exceed 0.01 mSv/h are posted with a clear sign bearing the radiation warning symbol and the word "Radiation". Each entry to a room or clearly defined area where total radiation hazards exceed 1 mSv/h, are posted as "Radiation Restriction". Entries to each normally accessible area in which the loose contamination level exceeds the background value are posted as "Rubber Area".

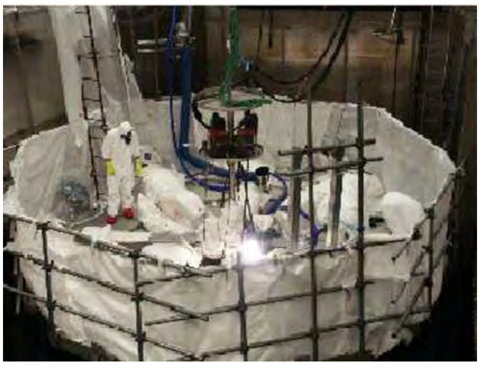
***Sweden: Dose predictions and check points for the moist separator modification (Forsmark NPP)***

During the 2003 outage at Forsmark Unit 2, a modification to the moist separator (an internal part of the reactor vessel) was planned. Early dose predictions showed a total collective dose of 250 man·mSv and individual doses near 20 mSv for several persons. The Forsmark Safety Committee, which has to approve all safety related work on the reactors, required that a set of check points be established. At these check points, work should be reviewed and evaluated with participation from the Unit Manager and the Radiation Protection Manager. Check points established included:

- Factory acceptance test to verify the contractors working methods and tools: check for labour time required.
- Lifting of reactor vessel head: check for source term accuracy.
- Following installation of shielding steel plates: check the actual dose rate against targets.
- During work performance: continuously check collective and individual doses. Constraints were set at the maximum collective dose of 350 man·mSv and maximum individual dose of 12 mSv.

Continued planning with the contractor resulted in major improvements regarding radiological safety. The work plan was reviewed and modified at each check point. The actual work was performed according to the modified plan without any complications, incidents or accidents. Daily meetings were held between contractor, operational staff and radiation protection staff. During these meetings, the resulting doses were closely monitored and communicated to all involved. The total resulting collective dose was 165.5 man·mSv and the maximum individual dose was 10.3 mSv (welder). The involvement of a highly professional and engaged contractor at an early stage greatly promoted the output.

**Working area with protective measures implemented**



### 7.4 Remote monitoring systems

Remote monitoring systems (RMS) with pre-set alarm levels (e.g. for dose, dose rate or airborne activity) provide a reliable means of real time monitoring of the radiological conditions to which a worker is exposed. A radiation protection control room may gather all information on the radiological conditions at various working areas, as well as voice and visual feedback, with a minimum presence of RP technicians in radiation areas, therefore reducing dose to such personnel. The same method can be used to survey other critical parameters from a place outside the radiation field (i.e. survey of automatic welding, cutting, in-service inspection). Research and benchmarking of remote monitoring technology conducted in several countries over many years has shown the effectiveness of such technology for improving worker safety and productivity.

A key element in the successful implementation of RMS is the availability of containment penetration for cable access. As this is a costly process, it is important to consider this, in addition to adequate electrical connections (auxiliary power/plugs) to power the equipment, at the design stage (see Chapter 9). The installation of an optical fibre communications network in the auxiliary building is also beneficial for permanent RMS.

***Canada: Teledosimetry (Ontario Power Generation)***

Remote or wireless technology for monitoring of personnel radiation doses is an under-utilised asset in today's Class I and Class II nuclear facilities. The current landscape in this field continues to advance as new users come on board. Ontario Power Generation's nuclear facilities have been working with these technologies since their early stages. OPG now employs IP fibre technology for data, voice and video signal transfer. These advances provide a reduction in setup time and lower production and maintenance person dose costs.

***Korea: CCTV system for radiation work management (Yonggwang NPP)***

The CCTV systems introduced in Yonggwang Units 5 and 6 are connected by LAN and enable real time monitoring of the work situation. The system has fixed and movable cameras. In the removal work of Thermal Sleeves (T/S), about 15 persons supervised the work through CCTV during the working period. The working time was optimised, and as a result, an exposure reduction of 16% (25.6 man·mSv) was achieved, as well as a reduction in the radioactive waste. The CCTV system makes a large effect with minimum effort.

***Romania: Remote monitoring systems (Cernavoda NPP)***

The RMS at Cernavoda NPP Unit 2 consists of a local area network of computers and a few network branches from field equipment to computers. The RMS interfaces with the following systems: fixed gamma area monitoring, fixed contamination monitoring, portable radiation monitors, fixed tritium in air monitoring, liquid effluent monitor, gaseous effluent monitor and post accident air sampling. Functions include:

- Monitoring: survey radiation hazards generated by normal plant operations and indicate high (dangerous) levels in the radiation control service (RCS) room and main control room (MCR); survey the working status of the measuring loops.
- Control: establish the set-up parameters for automatic operation of the channel; manually operate the measuring loop for non-routine measurements/calibrations; configure the network database.
- Maintainability: indicate equipment and system failures in RCS and MCR rooms.
- Data storage: maintain integrated short and long term database.
- Operator interface: provide customer reports, detailed display of historical events, remote interactive control functions for the field radiation monitoring equipment, including the display of the commands and their response.

***United States: Remote monitoring***

US plants have experienced a two-fold decrease in RP department dose during outages after the implementation of remote monitoring. Fewer technicians are dispatched to the work area since a single technician at the central remote monitoring console can monitor and control multiple jobs. For example, at Calvert Cliffs, between 1999 and 2006, the number of RP contractors as well as the number of RP permanent workers have been reduced by nearly 30% during outages. In the same time, the total offline collective exposure was reduced by 55%.

## 7.5 Control of contamination

Control of airborne contamination should be done using appropriate monitoring systems. Special attention should be given to the location of such systems, as well as to the avoidance of false alarms, which could result from contamination alarm levels that are set too low or improper placement of the monitors. Specific emergency evacuation procedures to be implemented in case of an alarm must be planned in advance and known by workers. The presence of a reactor building co-ordinator in charge of assistance and control of the evacuation can facilitate the procedure.

***Germany: Covering the reactor pool against airborne activity***

Some German PWRs (Philippsburg, Neckarwestheim, Isar) have used balloon silk to cover the reactor pool before its refilling during the outage. Two mobile ventilation filtering fans catch any aerosols beyond the cover and transfer them to the ventilation system of the reactor building. The advantages of this process are:

- No release of airborne activity into the containment and no induced contamination in the reactor building.
- No need of large decontamination works in the reactor building.
- No restriction for the workers caused by carrying additional clothing or respiratory equipment.
- No limitation of the number of persons in the containment because the personal lock remains open during the refilling time.
- 50% to 70% reduction in the refilling time (8 to 10 hours) on the critical path of the outage.

***Romania: Tritium in air monitoring system (Cernavoda NPP)***

Tritiated water vapour is a health hazard and its early detection in CANDU nuclear plants is important because it has all the characteristics of water vapour in the atmosphere. The monitoring system indicates levels of tritium generally due to heavy water leakage, thereby reducing the possibility of health hazards. The system performs the following functions:

- Continuous sampling of air from various locations in the reactor building and service building where a high H-3 hazard is expected.
- H-3 concentration measurements on continuous samples and comparison of the measurement results with a preset value (set-point) established by the operator.
- Display of tritium concentration activity ($Bq/m^3$) or on request, equivalent dose rate (Sv/h).
- When the set-point is exceeded or when a failure occurs, the system alarms remotely throughout the RMS network by visual and acoustic signals.
- "Non-routine" tritium concentration measurements using the temporary sampling lines and semi-portable tritium monitors.
- Tritium monitors should satisfy the following performance requirements:
  - Measure tritium oxide and provide compensation for other radioisotopes, including all reactor gases as well as radon.
  - Provide alarms for high dose rate level above an adjustable set-point and for equipment failure.

***Sweden: Monitoring of external contamination (Forsmark NPP)***

At Forsmark NPP, the following procedure has been adopted for controlling contamination.

Walk-through monitor: Actions upon an alarm

- Wash hands, change coverall and protective shoes and enter monitor once again.
- If an alarm still occurs, contact RP group.

Pre-monitor: actions upon an alarm

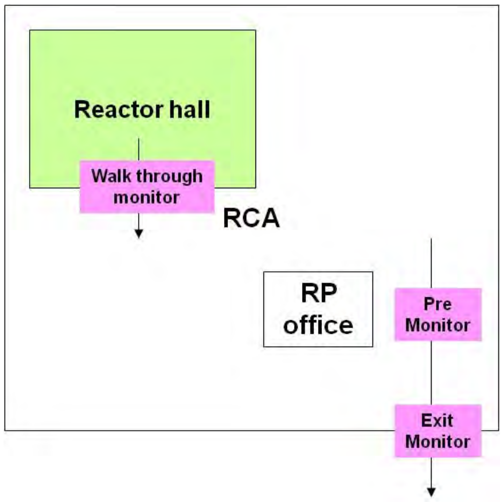
- RP personnel will investigate and document where and with what the person has worked.
- Wash hands, change coverall and protective shoes and enter monitor once again.
- RP personnel performs manual monitoring and decide upon further actions.

Exit Monitor: Actions upon an alarm

- RP group shall be contacted.
- An alarm is also sent to the RP office (during night to the Security Centre) and also a video view from the monitor area is shown.
- RP personnel arrives at the monitor area and decide upon further actions.

Since these routines were implemented several years ago, Forsmark has been able to achieve:

- Faster and more accurate reaction on the spreading of contamination in areas or in connection with specific jobs including performing countermeasures regarding cleaning and protective equipment. This also prevents occurrence of internal contaminations.
- Lowering of ALARA goals regarding the number of alarms given, out of the total number of measurements in the exit monitors, from 2 to 0.5%.
- Giving personnel even more confidence that their safety and working environment in the RCA is being addressed.
- Raising the level of knowledge among the RP staff on how and where contaminations usually occur, and also that contamination occurrences are well documented.




### 7.6 Avoidance of unnecessary dose and reduction of transit exposure

Transit doses refer to doses received by workers on the way to the job location. To reduce such doses, workers should be provided all necessary information on the working area. The provision of detailed site maps at the entrance of the reactor building, at various locations inside the building, in work procedures and during pre-job briefings can help to reduce the transit time of workers and therefore unnecessary dose by accurately locating the job site and providing optimal directions. This is particularly relevant for work on small valves, which are often difficult to find. Information on dose rates is also important, especially if there are hot spots along the transit path.

Clear signage for indicating both hotspots as well as low radiation areas is important reducing dose, and can include for example:

- Flashing hotspot signs or ropes (battery powered, LED with passive infrared sensor).
- Motion-sensitive audio signs providing pre-recorded warning messages.
- Multilingual signs to assist crews/contractors from other countries.
- Bright green low radiation area tarpaulins.

The use of advanced imaging tools (see Section 5.3) to allow workers to take a virtual tour of the area of interest is also very useful for orienting workers and for familiarising them with the work site with no cost in dose.

In order to reduce the time spent in high dose rates areas, it can be useful to identify low dose rates areas so that the workers can read their working procedures, prepare their jobs, or wait for their part of the work procedure with less exposure. Locating work benches and tables in low radiation areas is one example of this approach.

Finally, it should be noted that operational dose rate control is also important to avoiding unnecessary dose. This can be accomplished only with efficient communications and work co-ordination. For example, the effective control of "transient" high dose rates from hot spots in piping systems requires hot-spot identification (by workers and/or RP staff) followed by line flushing or hot spot shielding. In that these hot spots are, by nature, transient, follow-up surveys are also necessary.

***Finland: Break rooms***

To minimise the time spent for coffee breaks, Finnish plants have installed break rooms where workers can have a coffee break without having to change out of their controlled-zone protective clothing. The break room is situated between a monitoring checkpoint (workers must pass through portal monitors and meet 4 Bq/cm contamination levels before entering the break room) and the "step-off pad" leading to the dressing rooms. Toilets are also available in the break room. By this technique, the time spent on "coffee breaks" has been reduced from approximately 50 minutes to less than 20 minutes.

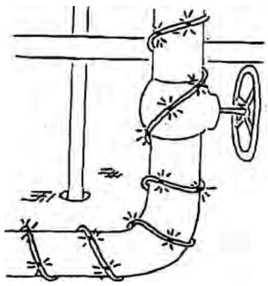
***France: Avoidance of unnecessary dose***

At EDF, a specific procedure is applied when gamma-radiographic inspections are performed: an "exclusion" area is defined (no workers are allowed to enter this area during the test) and indicated on generic building maps posted at various places in the reactor building. At all entry points to this area, specific signs are posted indicating that entrance is forbidden due to a high radiation risk and a radiographic control.

EDF is identifying "Green (ALARA) areas" at several levels in the annulus of the reactor building. These areas are clearly indicated. As an example, such an area is often established just outside the reactor building personnel entrance hatches. It is of course important to educate the workers on the use of these areas to ensure that they are using them as often as necessary, but not too much (they are not supposed to be rest areas).

***Japan: Use of visual reminders***

In Japan, a visual reminder is used to inform workers of high or low radiation doses. Colour light-tubes have been introduced in Japanese BWRs to indicate high radiation fields (red) and low radiation fields (green). These light-tubes are made of flexible, transparent polyethylene and contain small coloured bulbs at approximately 30 cm spacing, which can be hung on equipment, handrails, walls, etc. to indicate areas to be avoided or to use as waiting areas. They can be connected to area radiation monitors and will change colour according to the dose rate. The following figures illustrate the use of these light-tubes.



Moreover, Kyushu Electric Power Co. Inc. uses the following signs to call a worker's attention to high radiation areas and to provide information on waiting places:

- Red (≥ 0.5 mSv/h): Pay attention to radiation! Do not approach! Do not halt!
- Yellow (< 0.5 mSv/h): Pay attention to radiation! Do not halt!
- Green Cross: Waiting place (used in conjunction with a green polyethylene sheet).

***Switzerland: Avoidance of unnecessary dose (Beznau NPP)***

At Beznau NPP, signs indicate the level of classification as well as the measured dose rates (ambient, on contact, at 1 m etc.) of each zone when the level of classification changes within the same room or between rooms. Moreover, in the health physics office at the entrance of the controlled area, there are maps indicating the ambient dose rates at various points in the reactor building and the nuclear auxiliary building depending on whether the unit is in operation or stopped. These maps are also displayed in some parts of the controlled area. There are also "RP islands" at various points in the controlled area, in particular in the reactor building. These zones, in which the dose rate is very low, are used as fallback zones for workers during work.

***United Kingdom: Item location plans (Sizewell B NPP)***

At Sizewell B, "item location plans" are displayed at the entrance to the reactor building. All moderate and high radiation area rooms have "radiation contour maps" displayed. These include a layout of the room, locations of valves etc. and the position of the relative high and low radiation zones. Furthermore, "health physics information sheets" are produced for all valves, welds and snubbers to be worked in moderate or high radiation areas. These include a photograph of the item, a summary of the radiological conditions, recommendation for approach routes and the best time to schedule work on this item. On the reverse is a plan showing the location of the item, plus the nearby hotspots and low radiation areas. A map of the main circuits and valves is put on the wall at the entry of each high dose rate area. These so-called doserate contour maps show high and low dose rate areas. Information sheets are produced by health physics for many plant components with photographs, location maps and radiation dose rate information. Workers can also get to know their work area with a Surrogate-Tour® software.

Reactor building access control is increasingly important as the airlock capacity often limits the number of people able to enter containment. Sizewell B has adopted a quota system which is enforced by a guardian, however this is not very efficient or effective as the personnel acting as guardians are usually short-term contractors with little knowledge of the work plans. Where practicable, plants should use the security or dosimetry access controls systems to control numbers in containment.

### 7.7 Avoidance of rework

The need for rework may result from poor design, construction, planning or implementation. As part of good work management, it should be remembered that doing a job fast but poorly may mean redoing it or doing more work to correct the problem.

This may require not simply repeating the same work, but of correcting any secondary impacts (for example, the cost in terms of money and dose to remove a screw that has been forgotten in a pipe and which has subsequently damaged steam generator tubes etc.) The delay created by such rework may be several days if the reactor must be cooled and the pressure taken down before rework can take place, after which the temperature and pressure must be raised. This delay will also cause "secondary" doses from other jobs. Such jobs are, for instance, plant operations that must be repeated upon every start-up, and any job which will progress slower because of the additional available time. In an ALARA perspective, any rework should be identified during the outage to estimate their consequences in terms of individual and collective dose as well as to learn their causes to avoid reoccurrence.

Utilities should take advantage of the information in ISOE to review experience on repetitive jobs in sister plants to gain insight on rework avoidance.

### 7.8 Waste management

Waste management is an important part of work management during all phases (construction, work planning and work implementation). In order to avoid unnecessary doses it is important to take into account, in planning and in work implementation, aspects such as logistics (waste should be transported out from working area as soon as possible), sorting of waste as near to the source as possible, the need for intermediate storage and methods for final disposal. The optimisation process includes the aim that as much waste as possible be cleared and treated as non-radioactive waste.

***Sweden: RadWaste sorting stations in the RCA (Forsmark NPP)***

To reduce doses, costs and the load on the environment by minimising radioactive waste, Forsmark NPP introduced a system to sort waste at the source in the RCAs. At several locations in the plant, waste sorting stations have been established where the worker can easily separate the waste produced by the work. By sorting the waste, materials that need not be disposed as radioactive waste can be separated from more contaminated materials. The sorting station has around 10 different compartments into which the worker puts the waste according to well defined and displayed categories.

At the sorting stations the worker separates, for example:

- Solid waste with a maximum dose rate < 0.3 mSv/h.
- Soft waste (such as tissues, plastics, fabrics) with a dose rate < 0.3 mSv/h.
- Supposed non-contaminated materials, which after being checked by an RP technician can be cleared and be disposed of as "regular" waste without radiological restrictions.
- Material from rooms with low or no contamination.
- Electronic waste, batteries, light bulbs and fluorescent lights, chemicals and spray-cans, each in separate containers.

Waste from rooms with low contamination often pass clearance levels even if it is produced inside the RCA. Other materials can be disposed in shallow land burial at the site instead of putting it in the rock caverns of the underground repository, SFR-1.

## 7.9 Collection of feedback during work implementation

The collection of feedback data is essential during the work implementation phase to inform the work being undertaken. Real-time feedback allows ongoing evaluation of the dose evolution, work optimisation and rapid implementation of corrective actions in case of dosimetric "drift". Dosimetric results should be displayed in a visible place, for example at the entrance of the reactor building or in the dressing room. During the outage, providing the comparison of the evolution of actual and predicted collective dose encourages worker participation in the global ALARA efforts of the plant. Key messages can be added to motivate workers towards reaching the outage goals. For example, in France and the United Kingdom, some plants have experimented with the daily display of the evolution of actual and predicted collective dose for the outage, which has been very well perceived by the workers. A more complete discussion on work feedback is given in Chapter 9.

***Japan: Personnel qualification and exposure monitoring system***

All Japanese nuclear plants have personnel exposure monitoring systems which enable the plant to:

- Confirm worker information (ID, current annual exposure, training and medical examination history) at the entrance of the controlled area.
- Monitor individual exposure per entry by electronic dosimeter and compare it with the dose limits.
- Collect individual exposure, and time spent in the controlled area.
- Sort exposure by individual, work code or group of workers.

***Romania: DOSERECORDS system (Cernavoda NPP)***

Recording and storing worker doses are required by regulation. The radiation protection department provides individual (external and internal) dosimetry surveillance for all persons (employees, short-term workers, contractors and visitors) who enter the controlled area. Doses management is performed with a database called DOSERECORDS, for correct and complete dose records on electronic and paper format, and to keep all the analytical results and personal IDs. Each employee, health physics staff and regulator can access the dose information and generate reports.

***Switzerland: PERDOS software***

In the PERDOS (personnel dose data collection, monitoring, and reporting software) system at Beznau nuclear power plant, electronic dosimeters are linked to the plant's computer system, which enables individual dosimetry to be monitored in near real-time. In particular, this programme is used to:

- Monitor the dosimetry of each worker (both NOK staff and external contractors) per year (since 1989), per month, per day or per job (the date, time and duration of presence in the zone are available).
- Determine the maximum dose rate to which the worker has been exposed.
- Sort the sheets by group of workers, by level of dose received.
- Send some specific data directly to the safety and radiation protection authority.
- Compare forecast and actual collective doses during outages etc.

***United Kingdom: Sizewell B engineering computer system (ECOS)***

Sizewell B power station is using a powerful tool to monitor the plant – the engineering computer system (ECOS) – available to the operational health physicist. ECOS records readings from around 20 000 different sensors around the plant every two seconds. Of immediate interest to the health physicist are the area gamma radiation monitors, containment activity levels, stack activity levels and activity levels in HVAC ducts. Information is also available about system temperatures, pressures, tank and sump water levels, valve positions and pump running states. All of this data is available live time or can be retrieved for historical review.

## 7.10 Summary

The implementation of quality work is the goal of effective work planning and preparation, and is an important opportunity to influence the cost, time and dose associated with a particular task. The principles of work management, if applied at this phase, can help in optimising these three aspects of work. The use of work process controls, the provision of appropriate information to workers, the collection of feedback information, and the motivation of workers are all areas where effective work management can optimise work in many ways.

# 8. WORK ASSESSMENT AND FEEDBACK

*The philosophy of work management is a continuous loop that consists of scheduling, planning, implementing, assessing, following-up, making modifications as per lessons learned and repeating the process for the next job to be undertaken, thus making the work cycle progressively optimised and in line with current technological developments. "Assessment and feedback" is the final stage of work and, at the same time, the first stage of the continuous loop.*

## 8.1 Introduction

In a generic approach, two levels of information may be necessary to provide complete feedback on work implementation: the "internal" level, which consists of an analysis of in-plant performances, and the "external" level, which will provide national and/or international data favouring the exchange of new ideas and allowing the plant to assess its position with regard to other plants of the same type.

Various information sources may be available for job dose assessment, such as the in-plant radiation exposure monitoring system database or corrective action programme, and corporate-wide, industry-wide and international databases of ALARA practices. The job review and the appropriate follow-up are among the most important parts of any task evolution. The ISOE database, the world's largest database on occupational exposure from nuclear power plants, provides an important global resource for benchmarking analyses and exposures trends.

Normally, follow-up will lead directly into the next implementation of the operation under consideration. The lessons-learned, both good practices and areas for improvement, should be collected in a diligent manner, and exchanged not only with the work team but also with colleagues at the plant, industry and international levels. RP managers should recognise all available information sources and use them effectively as well as share their own information and experience. Finally, work management implementation should be audited periodically to assure that it is functioning properly.

## 8.2 Job review and follow-up

The extent and nature of a post-job review will vary depending upon the job being reviewed, as larger jobs will require more in-depth review than smaller jobs. Flexible criteria for helping to decide which jobs should be reviewed (such as total collective dose, the total number of person-hours, the percentage of over- or under-estimation of the total collective dose and/or the total number of person-hours etc.) should be established to guide job reviewers. In general, the review should be conducted by a multi-disciplinary team. The objective of the review should be to establish what aspects of the job were performed well or poorly, and which could be performed better, and how, in the future.

The workers having performed the work should directly provide their feedback on the work, how it could have been improved, or how the problems encountered could have been better addressed. Such information can be collected by way of post-job briefings (Appendix 4). It is also possible to organise specific meetings with contractors at the end of the outage, although this may involve paying the contractor to remain at the site after the completion of the work.

The use of "suggestion forms" (Appendix 5), available during the outage, where workers can propose various actions to reduce exposures is also a good way of collecting relevant feedback. In order to encourage workers to complete such forms, it is necessary to provide them feedback on how their suggestions have been analysed and how they might be taken into account. The management of these forms must be well organised, and it is essential to designate one person (or a group of people) to be in charge of collecting and analysing the suggestions.

The preparation of outage reports, which include technical and radiation protection data, is essential. Such reports must include analyses of the causes of deviations from outage goals (in a positive or negative way), recommendations for improvement, and identification of "good practices". These reports should be widely distributed within the outage structure.

To close the work management loop, a mechanism for assuring the incorporation of job feedback is necessary. In order to ensure that appropriate recommendations are implemented, formalised systems such as tracking lists or informal systems such as simply maintaining the post-job review team intact for the preparation and planning of subsequent work have been utilised. In either case, input from the post-job review team is essential to the appropriate follow-up of work.

It can be useful to organise, after the outage, one or more multi-disciplinary meetings devoted to the analysis of the outage, to identifying the follow-up actions to be implemented, and to assigning responsibilities for the completion of those actions. These decisions may be taken by the ALARA Committee, when it exists, or by a more general "Outage Analysis" group. In either case, such a follow-up group should exist on a continuous basis, changing roles from outage follow-up to outage planning as the next outage arrives. This will help assure the appropriate continuity of experience from outage to outage. It should be noted that such year-round coverage philosophy generally exists in most countries.

***Japan: RV core internals replacement (Ikata Nuclear Power Station)***

Replacement of core internals (CI) was performed at Ikata-1 in 2004. The total dose was below $1/10^{th}$ of the planned dose. The main contributors were the lower dose equivalent rate of the CI storage container and various measures to reduce radiation exposure, such as careful pre-job study, mock-up training, temporary shielding (RV head cover and worker waiting area in the reactor cavity), remote operation to install the bottom plate to the container, and a warning sign of dose equivalent rate on the RV head. The lessons-learned were incorporated in a similar job at Ikata-2. Main improvements were due to:

- Changing the working place used to dry and weld seal the plate of the container from the inside-containment vessel to a new maintenance building where the dose rate is lower.
- Shortening working time by partially optimising the specific work and employing experienced workers.

The total collective dose at Unit 2 was slightly higher than at Unit 1 due to the higher dose rate on the container surface (Unit 1: 0.6 mSv/h; Unit 2: 0.70 mSv/h) and the slightly higher source term at Unit 2.

**Doses for CI replacement at Ikata Unit 1 & 2**

| | | Actual | Planned |
|---|---|---|---|
| Total dose (man·Sv) | Unit 1 | 0.14 | 1.8 |
| | Unit 2 | 0.21 | 0.28 |
| Individual maximum dose (mSv) | Unit 1 | 4.50 | 20 |
| | Unit 2 | 6.58 | 20 |

***Japan: ALARA target process with planning, work review and follow-up (TEPCO)***

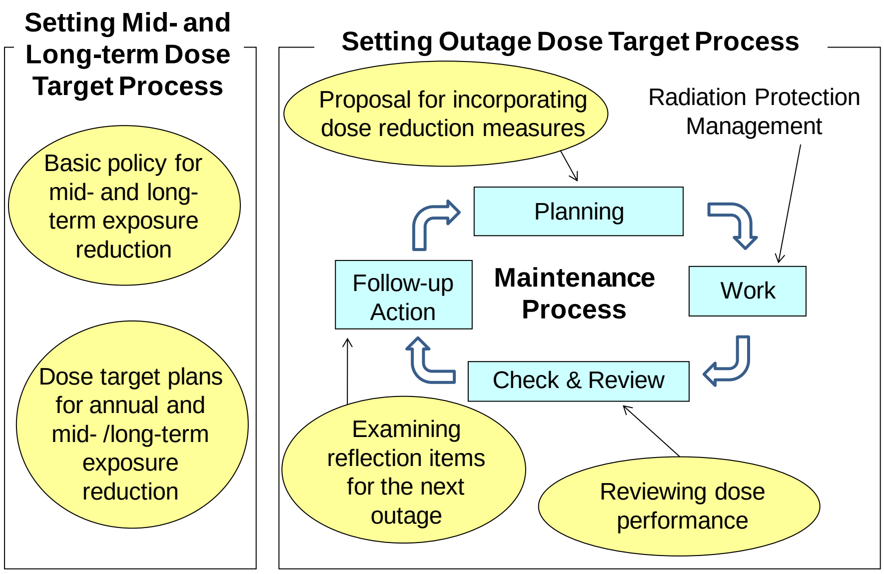
A Dose Target Control Peer Team, which consists of RP, Chemistry and Maintenance staff from all sites, has been organised to improve the ALARA programmes. The conventional ALARA process was reshaped by:

- Reviewing the "as-is" ALARA process.
- Identifying a gap between the "as-is" and the "to-be" process.
- Focusing on the interface between the RP and maintenance work process at planning and post-outage steps.

The objective is to incorporate ALARA considerations into the work process more efficiently and effectively. The team aimed to improve two main processes: setting the mid- and long-term dose target and setting an outage dose target. The second process focuses on three job steps: work planning, review and post outage. In these steps, RP staff communicate with maintenance staff/contractors with respect to:

- Proposed dose reduction measures before outage contract.
- Information of detailed work schedule.
- Outage report with lessons learned.

The process has been implemented since 2007.




***Romania: Outage reports (Cernavoda NPP)***

At Cernavoda NPP, all activities during a planned outage are performed based on the approved work plan. For the duration of each activity, one person is assigned to follow and record all related aspects. After the work, a report is issued which notes problems and whether the work implementation was according to the work plan. A complete outage report is issued at the end of the outage, and includes:

- Personnel involved.
- Dose target (estimated collective doses) and collective received doses.
- Analysis of the task with collective doses greater or smaller than the estimates.
- Work group dose distribution.
- Collective gamma dose for all the tasks (cumulative and day by day).
- Collective internal doses due to tritium intakes.

The report is presented to all plant personnel and to the regulatory body. Corrective/preventive actions are established based on the conclusions.

***United States: Pressuriser heater sleeve replacement (San Onofre NPP)***

In 2004, San Onofre Unit 3 replaced two pressuriser heaters and Alloy 600 sleeves. Major challenges were radiological exposure and contamination control. Engineering controls consisted of lead shielding, HEPA ventilation, vacuums, work area containment and sleeving. Improved work practices, teledosimetry, and temporary shielding on the sleeves, surge line and work platform saved 170 man·mSv (17 Person·Rem) of exposure over the original dose estimate of 816 man·mSv (81.6 Person·Rem). Total exposure for the outage was 645 man·mSv (64.5 Person·Rem); the highest individual exposure was 16.85 mSv (1685 mRem). Lessons learned from similar work at Palo Verde were freely shared and were very helpful to San Onofre.

Work at San Onofre Unit 2 included the replacement of all Alloy-690 pressuriser heater sleeves. Substantial work process improvements were made between the first pressuriser heater half-sleeve repair project in Unit 3 and the current Unit 2 nozzle replacement. The collective dose estimate for Unit 2 was 390 man·mSv (39 Person·Rem). The total expected exposure was approximately 300 man·mSv (30 Person·Rem), which resulted in a reduction of more than 50% from Unit 3. Worker practices by the welding contractor improved significantly. A majority of the welding workforce were involved in an earlier Palo Verde pressuriser heater sleeve repair project. The use of experienced workers resulted in significant radiological dose reduction. The key successes were improved tooling used by the vendor, mock-up training, experienced workers and work planning.

## 8.3 Operational experience databases

While post-job reviews are important for obtaining worker feedback, the use of computerised data management systems for the collection, storage and analysis of operational and baseline data is essential for ensuring that feedback is efficient, complete, recorded and available for benchmarking and analysis. For such systems, both internal and external data are useful, including data associated with a particular task or class of tasks, such as working time, manpower, equipment, dose etc. At the internal level, this data can be collected directly before, during and after work. Computer-based systems, most easily associated with the operational dosimetry system, can be very efficient at collecting this type of information.

To optimise radiation protection actions for jobs with high radiation exposure potential, a step-by-step estimation of working time and associated dose is accepted as a good practice. The results of such calculations provide a good tool for tracking work progress and allow the early recognition of possible problems. For this purpose, an on-line computer based dosimetry system is required, and should interface with the work permit system, giving the dose, status of ongoing work and time at the work site (not just in the controlled area). The different teams involved (mechanical, electrical, scaffolding, health physics, industrial safety etc.) should support the gathering of all available experience, as this forms a valuable base for the planning of similar tasks. Data must be open to all facilities contributing to planning and scheduling, and updating of work status must be the responsibility of all organisational groups associated with the job.

Proper documentation of all job, component and working area related information is necessary input for operational databases which can be used during the assessment phase and for the preparation of the next outage (Chapters 5 and 7). In order to create operational experience databases that are as complete as possible, it is important to collect a broad range of multi-disciplinary data, including dosimetric data, information on the general course of operations etc. This will allow effective benchmarking and permit analyses of unexpected events and deviations between the predicted and recorded doses. Such databases exist at the local, national and international levels.

One difficulty regarding such data collection lies not so much in the integration of data into computerised database management systems, but in the direct capture of raw data. One efficient procedure is to use records that are systematically completed, either by the radiation protection staff or by the job foremen, at the end of the operation. Relevant information includes dosimetric data (total collective dose, individual doses etc.), data describing the working environment (ambient dose rates, contamination, type of protective clothing, "job ergonomics" etc.…) and, when appropriate, precise details of any malfunctions encountered, their causes and a quantification of their impacts in terms of time and dosimetry. Particular attention should be paid to completing these records, as this impacts the quality and precision of the final information used for past experience analysis. While being sufficiently simple so as not to be seen as a constraint for the responsible person, these records must be designed for easy incorporation into the data-processing system: planning of the chronological order of the questions for data capture; prior coding of certain variables when possible etc.

***ISOE: ISOEDAT global occupational exposure database***

Participants to the ISOE programme have access to the world's largest database on occupational exposure at nuclear power plants, providing detailed exposure data at 470 reactor units (operating and under decommissioning) in 29 countries. The database can be accessed through the ISOE Network website (www.isoe-network.net) or on CD-rom, and allows users to benchmark dose results against various NPPs (by reactor type, sister-group, etc.) on the basis of annual collective dose, outage doses, dose per job etc. Information on the RWP man-hours and some specific dose rates are also included in the data base. For each NPP, a contact person is identified allowing the participants to contact directly the plant if more information is needed.

***France: End-of-job reports***

At EDF plants, contractors have to write an "end job report" for high dose jobs. These reports contain the following information regarding the RP part (a technical part is also included in the report): comparison between planned and actual exposure, with explanations of differences, dose rate and contamination maps, identification of mishaps, RP actions, good practices etc.

***United Kingdom: Capturing lessons learned (Sizewell B)***

At Sizewell plant, about one month after each unit outage, all HP interveners (from each group, including contractors) meet together for establishing lessons to be learned. In complement, they can take information from the "Lessons Learned" database, which can be filled by anyone who wants to do so (both paper and computer forms are available). A specific HP feedback experience report is also written for the main jobs performed during the outage, especially those for which pre-job ALARP briefs were conducted including dose assessment, dosimetry results, personal contamination events, lessons learned (what worked and what did not) and recommendations for the next outage. Moreover, a general "HP outage report" summarises the last outage as far as radiological protection and radwaste aspects are concerned. Good practices and areas for improvement are highlighted in this report. This report is sent to inspectors (NII), the Station Manager, FMA and RWE (contractors workers group and HP subcontractor), British Energy HP Headquarters, laundry etc.

### 8.4 Comparison of ALARA practice

In terms of work assessment, the indicators used to assess work and the benchmarks against which they are judged, must be multifaceted. For example, collective dose and individual dose distribution must be accompanied by other indicators such as person-hours, number of workers, work duration, re-work required, delays and problems etc. For such benchmarks and indicators, data from pre- and post-job ALARA analysis, historical data and data from other sites is essential (see Sections 5.6 and 7.9).

Building on the information collected in post-job reviews and contained in operational experience databases, it is possible to compare ALARA practices and job collective dose within the same NPP fleet and sometimes similar jobs between different plant designs. A common comparison basis can be established by grouping different plant designs according to sister groups, as has been done within the ISOE occupational exposure database. ALARA related parameters, such as source or initial dose rate and plant system configuration can help define initial conditions for planning purposes.

When analysing and benchmarking operations, a structured method should be adopted. In order to identify the most important areas requiring action, a classification of the causes of reworks or mishaps can be used. For specific operations, “Time and Motion” studies allow the evaluation of the techniques used in performing the procedure, and target areas which will improve the overall efficiency of the process. These studies may also cover other areas such as: work station design, development of improved work methods and establishment of time standards.

For the analysis of dose trends for an operation which has been performed several times, perhaps in different ambient dose rates, it is necessary to “normalise” the dose in relation to a reference ambient dose rate. This normalisation allows the identification of the real exposed time spent for each job. It can be noted here that this type of analysis has shown that when the operation is performed in a low ambient dose rate after having been done in higher dose rates by the same team, workers tend to spend more time than necessary in the area because they are used to a certain level of exposure, and pay less attention when the dose rate is not as significant. This fact points out the need to provide workers with an estimated dose before each intervention, taking account of actual dose rates.

The ISOE Network website is also an important resource for ISOE Participants to review and share experience on major jobs (like steam generator replacements) and to establish contacts between radiation protection professionals at NPPs worldwide in order to discuss common problems or to organise, for example, benchmarking visits. The analysis of annual or outage doses can be used to select the “best” plants to be visited in order to share practical RP experience.

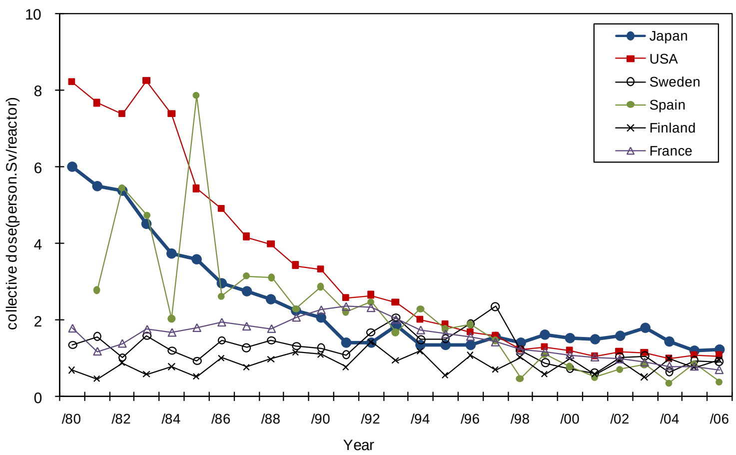
***Canada, Romania: CANDU owner’s group***

The Health, Safety and Environment (HS&E) R&D programme, managed by the CANDU Owners Group (COG), is jointly funded by Canadian CANDU reactor owners, SNN in Romania and Atomic Energy of Canada Limited. The programme addresses issues related to radiation monitoring, radiation protection and dosimetry, including the establishment of the risks of radiation exposure to workers, the public and the environment. Compliance with the requirements of various CNSC Consultative and Regulatory Documents is an important driver for the programme.

***Japan: Comparison of ALARA practices with ISOE***

The ISOE occupational exposure database and experience exchange network provides excellent opportunities for comparison of ALARA practices. Using the ISOE database, it was recognised that the Japanese average collective dose per reactor had not decreased since the early 1990s, whereas it had decreased considerably in other countries (such as in the United States).

**Average collective dose per reactor for operating reactors, 1980-2006 (ISOE, 2008)**



ATC co-operated with Japanese utilities to send questionnaires through the ISOE communication network to learn the reasons for this situation. Then, at the 2005 ISOE International ALARA Symposium, ATC discussed with NATC the possibility to coordinate benchmarking visits to US utilities. A series of visits was successfully performed in 2005 and 2006 with co-operation of NATC and US utilities. The results were shared with ISOE members at the 2007 ISOE International ALARA Symposium. The reasons for higher exposures in Japan include differences in operation cycle, duration of refuelling outage and maintenance criteria between Japan and other countries. The operation period that has been permitted in Japan is 13 months or less, and the duration of plant outage is about 2 to 3 months, which is about two times longer than that of other countries.

## 8.5 Sharing feedback experience

To complement the information available at the plant level, it is necessary that the plant remains in contact with other plants from the same utility and from others at the national and international levels. Participation at radiation protection meetings, in regional and international user groups, experience exchange networks, web-based information systems such as the ISOE Network website (www.isoe-network.net) and topical symposia such as the ISOE international and regional ALARA Symposia favours the exchange of information and allows workers to be aware of the new techniques. This strongly supports efforts to maintain doses ALARA.

***Germany: VGB***

In Germany, an organisation (VGB) gathering all the major German electricity utilities (nuclear or not) as well as utilities from some other European countries has been created. There is a VGB-group of health physics managers in which all German nuclear power plants are represented. This group meets twice a year at the site of one of the plants. Usual items for discussion include:

- Exchange of information, experience.
- Reports of special radiation protection actions.
- Regulatory developments.
- Discussion of specific radiological items: beta-dosimetry, internal dosimetry, ALARA-subjects, ISOE.

***Romania: OPEX process (Cernavoda NPP)***

At Cernavoda NPP, every employee has to report any observed abnormal condition, including near-misses. Many employees are registered on the “Information & Exchange” forum of the CANDU Owners Group (COG) website and are notified about external events which have occurred at other plants. Events that have occurred at other plants and that may also occur at Cernavoda are announced as abnormal conditions at Cernavoda and analysed for their likelihood of occurrence and for the need of corrective actions. The abnormal condition is analysed by the OPEX group and classified as “minor”, “important” or “event”. The last two classes are further analysed and the direct causes, contributors, and corrective actions are systematically established. An “event” will be reviewed by an interdepartmental team in order to establish root causes to prevent recurrence. Workers are briefed before the job on all information from external and internal sources. Corrective actions are followed up by the Quality Management Department. Metrics on abnormal conditions and the actions to be implemented are reported monthly with the station/department performance indicators. If one indicator is below target, corrective actions are initiated.

## 8.6 Programme audits

Finally, the entire system of work management implementation should be audited periodically to assure that it is functioning properly. Again, many systems, from very formal to very informal, have been used. The auditing system can be internal at the plant level, or if relevant, organised at the corporate level to obtain a global picture of all the plants belonging to the utility. Internal audit programmes should include verification of compliance with national regulations as well as with the utilities’ internal rules and objectives.

External audits, such as OSART (operational safety review team) missions organised by IAEA or Peer Reviews organised by WANO, are also very useful as they bring into the audited plant experts from other plants, favouring the "independence" of the audit while contributing to information experience exchange between plants:

- OSART missions are carried out only at the request of the relevant IAEA Member State, and are directed towards a review of items essential to operational safety. A mission can be tailored to the particular needs of a plant. A full scope review would cover eight operational areas: management, organisation and administration; training and qualification; operations; maintenance; technical support; radiation protection; chemistry; and emergency planning and preparedness. Depending on individual needs, the OSART review can cover the full range of review topics or be directed to a few areas of special interest. Essential features of the work of the OSART team members and their plant counterparts include the comparison of plant operational practices with best international practices and the joint review of ways in which operational safety can be enhanced.
- Peer reviews organised by WANO aim to help WANO members compare their operational performance against best international practice through an in-depth, objective review of their operations by an independent team from outside their utility. The review, carried out at the request of the plant, is conducted by an international team consisting of staff from other nuclear power plants, in other words, peers of the staff of the station reviewed. The team examines the plant's performance in key areas in accordance with specific performance objectives and criteria. WANO peer reviews give members an opportunity to learn and share the best worldwide insights into safe and reliable plant operation, and thereby improve their own performance.

***France: EDF methodology for the evaluation of radiation protection performance and management***

Within EDF, the radiation protection performance of each site is assessed using quantitative indicators mainly related to the annual collective dose of the plant and its results in radiological cleanliness. The radiation protection management is evaluated through a questionnaire addressing six main themes:

- Commitment of the plant management team in radiation protection and characterisation of its level of ambition.
- Quality of radiation protection management.
- Involvement of local and outside workers in radiation protection.
- Competence and efficiency of the health physics department.
- Operational control of radiation protection.
- Robustness of the process of transport of radioactive materials.

***Sweden: Results of an OSART (Forsmark NPP)***

In 2008, an OSART mission was conducted at Forsmark NPP. This mission studied all aspects of safety as well as the radiation protection programme. The mission report identifies good practices to be applied by other NPPs, as well as recommendations for improvements for consideration by the responsible authorities. The report was made available on the Swedish authority website, allowing the results of the mission to be better shared.

## 8.7 Summary

The post-job assessment of work and the elaboration of appropriate and necessary follow-up actions are among the most important parts of any task evolution. To properly perform such assessments, some form of benchmarking is helpful. With the extensive experience in the nuclear power industry, databases of national and international operational experience have become a powerful tool to support benchmarking by plants in all countries. In terms of post-job review, it is essential to have a multi-disciplinary team conduct the review and to include as much direct input from the workers, including contractors, as possible. The follow-up of recommendations and lessons learned should then, ideally, be performed by the same multi-disciplinary team which conducted the post-job review. Normally, follow-up will lead directly into the next implementation of the operation under consideration, such that a certain closure (job conception, scheduling, planning, implementation, assessment and follow-up, job modification as per lessons learned, scheduling, planning, etc.) occurs and the job becomes progressively optimised and appropriately modified to keep up with current technological developments.

# 9. ENSURING CONTINUOUS IMPROVEMENT

*While work management is an iterative process, it is also forwarding looking, seeking continuous improvement and continuous vigilance to ensure and maintain a high level of radiation protection. Such improvements therefore seek to incorporate, through information and experience exchange, lessons learned and ongoing technological advances to not only inform future work activities, but also in the longer term, new design, new build and new operations to ensure that doses are maintained ALARA.*

## 9.1 Introduction

Throughout the history of nuclear energy use for electric power generation, occupational radiological protection has always been an area of concern. With the rapid exposure reduction occurring in the 1980s, occupational doses were reduced to approximately one-quarter of previous levels. Continued efforts since that time have resulted in further but gradual reductions. This continuous improvement was enabled not only by the efforts of the electricity utilities and regulatory authorities but also by technological innovation. Since the 1990s, progress in international co-operation in the exchange of information and good practices through such programmes as ISOE, and the diffusion of the ALARA spirit as elaborated in ICRP recommendations, has also contributed greatly to exposure reduction.

There is a range of technologies in various fields relevant to exposure reduction. These include source term reduction technologies, decontamination technologies, and mechanisation, automation and remote monitoring technologies. Technologies for radiation protection and improvements in work efficiency have been broadly implemented in the nuclear industry, as shown in previous chapters. However, the development and further application of such technologies should be considered in light of the radiation protection issues that will become important in the future, including exposure reduction in newly constructed or newly designed plants (of potentially increasing importance), large-scale modification works expected to be needed in association with aging and lifetime extension of nuclear reactors, and reactor decommissioning.

Examples of some of these technologies and their applications have been discussed in previous chapters. This chapter summarises additional noteworthy technologies and work management aspects deemed relevant for ensuring continuous improvement in occupational radiation protection, with special consideration for new nuclear build (design and construction). It should be noted that the majority of these technologies and work management aspects are also applicable to further exposure reduction in plants currently in operation.

## 9.2 Source term reduction in the design and construction of new nuclear power plants

### *Clean plants*

In order to keep dose rates in nuclear power plants low, it is important to keep the quantity of corrosion products that could be brought into the reactor core and subsequently activated to the lowest possible level, in other words, to keep the nuclear reactor "clean" from the design and construction stages. Such efforts will also contribute to improvements in the integrity of system piping and devices.

***Japan: Measures for clean plants (Onagawa, Kashiwazaki Kariwa and Hamaoka NPSs)***

Anti-pollution measures have been taken at nuclear power stations in Japan, including Onagawa, Kashiwazaki Kariwa, and Hamaoka. The Onagawa NPS has been working, since the construction of Unit 1, on the realisation of a highly reliable clean plant with the least exposure possible through various countermeasures developed under the "Clean Plant Campaign." Of the countermeasures identified, "crud reduction measures" have been positioned as a top priority item for the realisation of a clean plant and have been thoroughly implemented.

Crud reduction measures can be classified as "crud generation control" and "crud removal". Measures implemented at Onagawa NPS are characterised by the "storage management" of the primary piping, which has been thoroughly implemented as part of its crud generation control measures, in addition to the measures implemented for crud removal. Since the system conditions vary with the characteristics of the construction/test/trial run periods, Onagawa NPS selected the most appropriate storage method for its particular conditions. For example, generation of corrosion products inside the piping and devices was inhibited as much as possible by adopting measures such as the wet lay-up method with hydrazine (avoiding to the maximum extent possible wet lay-up with only pure water) and the dry lay-up method with dehumidified air, according to the conditions of the system piping. In addition, a system was developed to monitor appropriate storage conditions. As a result of such countermeasures, the Onagawa NPS was able to restrict the quantity of crud brought into the nuclear reactor to an extremely low level. Today, Onagawa NPS maintains the highest class in regard to extremely low dose rate through the combined implementation of other dose reduction measures.

***Adoption of low cobalt materials***

The sources of cobalt, which are chief sources of occupational radiation exposure, are stainless steel containing cobalt as an impurity, nickel-based alloys, and Stellite (a cobalt-based alloy). Since stainless steel is used in large quantities as a major structural material for the primary system, its cobalt content is very important. Stellite, chiefly composed of cobalt, generates Co-60 through the activation of its corrosion products, and is therefore a major source of occupational radiation exposure. In order to control the generation of corrosion products, it is necessary to use materials with excellent corrosion resistance and less cobalt content. Efforts have been made worldwide to reduce the Co content of materials, and many plants have replaced such materials with those of lower cobalt content in applications such as pin rollers in the control rod system, heating tubes for feed water heaters (stainless steel), fuel springs (Inconel), some stainless steel materials for the nuclear reactor system, etc. For example, most of the Stellite used inside the reactor vessel of the latest KWU nuclear plant in Germany (KONVOI) has been replaced with cobalt-free materials to significantly reduce the dose rate of the primary coolant piping system.

The use of low cobalt materials needs to be taken into consideration from the design stage, and is especially important for materials with large surface areas placed in corrosion-prone environments. Low cobalt materials and alternative materials for Stellite have been developed. For example, EPRI has developed hardfacing NOREM™ iron-based alloys as a substitute for Stellite used for valves in nuclear power plants. Their use will enable the reduction of cobalt radiation sources that contribute to occupational exposure.

***Surface treatment within piping***

The accumulation of radioactive materials within piping can be prevented by forming in advance an oxide film on the surface of the stainless steel. Reducing the adhesion surface area by smoothing the material surface is also effective for the preventing accumulation of contaminants. Crud adhesion can be prevented by electropolishing the inside of stainless steel piping following the mechanical polishing undertaken during nuclear power plant construction or replacement of piping or devices. For example, valves and piping were mechanically polished and electropolished for the restart of Browns Ferry Unit 1 in the United States. In France, electropolishing of steam generator channel heads is now performed for steam generators replaced in old plants as well as for the new reactor EPR.

***Installation of filters***

*(a) Hollow-fibre filters*

Hollow-fibre filters are composed of an extremely thin hollow-fibre polymer material of approximately hundreds of µm to 1 mm in outer diameter with numerous micropores of approximately 0.1 µm in diameter. Characterised by an extremely large filtration area per unit volume (10 to 100 times larger than those of other membrane filters), the hollow-fibre filter can reduce the size of filtration equipment to less than other filter systems.

This type of filter was first introduced in Japan in 1986 within the condensate system of a BWR, with the objective of shortening the pre-startup cleaning time. Because of its excellent performance, it was then also used for purifying the partial condensate during power operation. Later, these filters were applied to the condensate system of many Japanese BWRs and PWRs. In terms of its cleaning performance in operating BWRs, while the filter inlet Fe crud concentration ranges from several thousand ppb (pre-startup cleaning stage) to several tens ppb (power operation stage), the outlet filtered Fe crud concentration is constant at 0.1 ppb or lower. In plants that came into service after 1993, a complete condensate purification system using this type of filtration was implemented with the chief objective of reducing the feed water Fe crud levels. The introduction of this system resulted in reduction of the feed water Fe crud level to 0.1 ppb or lower and thus significantly contributed to the exposure reduction of workers.

*(b) Pleated filters*

A pleated filter is a membrane filter in a pleated form, resulting in an increased filtration area. Pleated filters were first used in the early 1990s chiefly in the United States and have been improved since then. Since the pleated filter elements are burnable, and contain no powdered resins, they contribute to the reduction of radioactive wastes. In addition, pleated filters are characterised by their compatibility with the filter housing for precoat-type filter elements. They can therefore be used in existing plant systems simply by changing the element without modifying the filter housing.

## 9.3 Shielding at new nuclear power plants

As described in Section 6.4, an effective measure for dose rate reduction is radiation shielding. During outage work, temporary shielding is effective for dose control. However, in terms of the cost, time and dose associated with its construction and dismantling for each refuelling outage, permanent shielding is more effective. For the construction of permanent shielding, consideration should be given to the seismic safety of the shielding, construction space, and access and space for inspection. These problems are easier to solve at the design stage of the plant.

The Kashiwazaki Kariwa Nuclear Power Station (ABWR) has reduced radiation doses by implementing shielding for the reactor coolant cleanup system in the design/construction stage. In addition, movable permanent shielding facilitates access to devices, piping etc. Several BWRs in Japan are provided with movable permanent shielding facilities, and it has been reported that the time for jobs using such facilities was reduced by 10-20% and that dose rates were reduced by 20% at maximum compared with that of the temporary shielding system (lead sheets and blanket).

### 9.4 Remote monitoring systems at new nuclear power plants

Remote Monitoring Systems (RMS) technology is a topic of strong interest within ISOE (see Chapter 6). RMS technology has proved to be effective in improving both the safety and productivity of workers. RMS technology also contributes to the improvement of work efficiency, thereby shortening the duration of the refuelling outage. In new nuclear power plants, the central control centre for the remote monitoring system needs to be taken into consideration at the design stage. In addition, in order to use RMS technology efficiently, optical fibre penetrations need to be provided between the containment and the drywell. These penetrations can also reduce time to install cables during plant shutdown. The use of the RMS technology is expected to bring about the following benefits:

- Exposure and radiological control performance.
- Worker efficiency and accountability.
- Work data and process quality.
- Resource (staffing) optimisation.
- Equipment reliability.
- Cost reduction.

### 9.5 Robotics technologies in new nuclear power plants

As described in Section 6.5, robotics technologies are being used effectively in nuclear power stations to reduce occupational exposures. Previously, robots were single-function technologies intended for specific tasks such as refuelling and in-reactor inspection. However, with rapid progress in mechatronics, multifunctional robots capable of performing various tasks have been developed.

The use of robotics technologies is especially appropriate for high-dose radiation fields, under water, in tight or inaccessible spaces, in poor work environments etc. Mobile robots for general or multiple purposes have also been developed, including free-moving underwater robots used for reactor core inspection or preventive maintenance work. Robots have been developed and successfully used for the following specific functions:

- Reactor head inspection.
- Steam generator tube inspections.
- Inspection of nozzles of CRD systems.
- CRD exchange equipment.
- CRD decomposition equipment.
- RPV stud bolt tensioner.
- Automatic ultrasonic detector.
- Refuelling machine.

In addition, there may be other cases where robotics technologies can be useful from such perspectives as work efficiency improvement, cost reduction and radiation protection. In order to maximise their benefits, it is important to consider and develop their use at the design stage of a plant.

### 9.6 Maintenance-free components in new nuclear power plants

Inspection of components is a significant cause of occupational radiation exposure in nuclear power plants. While it is important to optimise inspection items and the frequency of inspection using risk (and other) information, it is also desirable to adopt maintenance-free components to the maximum extent possible. For example, in the construction of Olkiluoto-3 in Finland, maintenance-free components have been used in places which will experience high radiation levels, in addition to the optimisation of selected materials and the construction of shielding, as a means to reduce exposure.

## 9.7 Work management aspects in new nuclear power plants

In addition to technology-based aspects, continuous improvement in occupational radiation protection in new nuclear power plants will also be impacted by work management aspects. Training, feedback and risk-informed regulation are critical ALARA aspects of any new build. Work management will always be important in maintaining ALARA culture and avoiding complacency.

***Training***

As noted in this report, training is a key aspect of work planning and preparation. Mock-up training in line with real plant facilities is an effective means that enables workers to understand and master their own work procedures, resulting in such merits as the improvement of work efficiency, the shortening of exposure time and the improvement of work quality. Mock-up training is especially effective for work in high-dose radioactive fields, work using special tools or devices, and complicated tasks. In this case, the training must be performed in real plant facilities or in a place comparable to real plant facilities under the same environment and physical conditions as the actual work. At new nuclear power stations, it is also considered effective to build facilities for virtual-reality or 3-D simulation technology and use these as a means for education and training. Such technologies can be used for visualisation of the work site environment, simulation of work procedures etc.

***Feedback (benchmarking)***

Assessing work performance and taking corrective measures that reflect assessment results are not only necessary to successfully complete the planned work but also imperative for improving performance of similar work in the future. Such assessments need to be performed by a multidisciplinary team composed of members specialised in the relevant fields. However, in order to ensure continuous improvement, it is necessary to ensure continued and increasing participating in information and experience exchange activities at all levels. This applies not only to work planning for currently operating plants, but also to use such experience to identify issues that would be more effectively addressed at the design stage of new reactors. Such experience exchange should also consider experience arising from new designs as these evolve, in order to inform future designs.

***Risk-informed design***

Radiation exposure is always associated with the job performed. Therefore, reduction of the inspection frequency for devices, piping, etc, will directly lead to the reduction of radiation exposure. In the United States, for example, inspection items and test frequencies have been reviewed by the nuclear regulatory authority using risk-based information. Utilities have also optimised inspection methods by implementing on-line and condition-based maintenance, etc. This has resulted in improved capacity factors and reduced exposure. Risk informed inspection and maintenance have been successfully achieved in current plants, and risk informed design should be developed for new build.

# 10. CONCLUSIONS

Safety and radiation protection are the most important factors for the safe operation of nuclear power plants. Experience in occupational radiation protection has shown that radiation protection measures should be adopted in all phases of the nuclear power plant life cycle, from design to operation to decommissioning. This not only allows source term removal or reduction as part of design, but also consideration of how exposure reduction methods or procedures can be most effectively implemented during operation.

Many methods that can be considered by all those with a role in occupational radiation protection at nuclear power plants have been described in this report. This multi-disciplinary, practical experience in work management, based on lessons drawn from many years of nuclear power plant operations, in addition to approaches that are still under development or will be realised in the future, are important elements in the optimisation of occupational radiation protection and for ensuring continuous improvement in the face of current and future challenges and opportunities.

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*Appendix 1*

## ISOE PROGRAMME INFORMATION

ISOE was created in 1992 to improve the management of occupational exposures at nuclear power plants through the collection and analysis of occupational exposure data and trends, and through the exchange of lessons learned among utility and national regulatory authority experts. Since then, the system has grown continuously and now provides participants with a comprehensive resource for optimising occupational exposure management at nuclear power plants worldwide.

Membership in ISOE includes representatives from nuclear electricity utilities and national regulatory authorities who participate under the ISOE Terms and Conditions. The ISOE programme includes the participation of utilities and regulatory authorities in 29 countries. The ISOE database itself contains information on occupational exposure levels and trends at 470 reactor units worldwide (396 operating units; 74 in under decommissioning), covering about 91% of the world's operating commercial power reactors. To find out more about the ISOE programme: www.isoe-network.net

ISOE is jointly sponsored by the OECD Nuclear Energy Agency (NEA) and the International Atomic Energy Agency (IAEA). ISOE operates in a decentralised manner. A Management Board of representatives from all participating countries, supported by the joint NEA and IAEA Secretariat, provides overall direction.

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Four ISOE Technical Centres (Europe, North America, Asia and IAEA) manage the programme's day-to-day technical operations, serving as contact point for the transfer of information from and to participants.

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*Appendix 2*

## EXAMPLE OF ISOE 3 WORK RELATED INFORMATION REPORT

*Example of an ISOE 3 Work Related Information Report from the ISOE Occupational Exposure Database (ISOE, 2008)*

| **a. GENERAL INFORMATION** | | | | | |
|---|---|---|---|---|---|
| Name of reactor unit: | | | Year: | | Number: |
| Type of reactor: | | | Sister Group: | | |
| Status of reactor: | | | | | |
| Contact-person for ISOE 3: | | | | | |
| Phone: | | Fax: | | Email: | |

| **b. SHORT DESCRIPTION** | |
|---|---|
| Title: | |
| Description (in English): | |
| Starting date: | |
| Ending date: | |
| Total collective dose: | |

| **C. KEYWORDS** | |
|---|---|
| Operation performed keywords: | |
| Systems keywords: | |
| Components keywords: | |
| Radiation protection actions keywords: | |

| **d. FULL DESCRIPTION (may be written in your own language)** | |
|---|---|
| | |
| References to reports: | |

*Appendix 3*

## EXAMPLE OF A PRE-JOB ALARA CHECK-LIST

| PRE-JOB ALARA CHECK LIST | | | |
|---|---|---|---|
| | **Yes** | **No** | **To be studied** |
| Is there previous experience of similar operations?<br>Has it been taken into account? | | | |
| **I. Actions on sources** | | | |
| Before shutdown: chemical filtration?<br>Decontamination?<br>Is it possible to maintain water in circuits?<br>Removal of a highly radioactive material?<br>Other? | | | |
| **II. Protection** | | | |
| Biological shielding: is it fixed, mobile, integrated with the machinery?<br>Against contamination: is a glove box available?<br>Shielding?<br>Is shielding integrated with the tools?<br>Static containment?<br>Dynamic containment?<br>Sprinkling and drainage?<br>Adapted individual protection? | | | |
| **III. Volume of work under conditions of exposure** | | | |
| Is this an essential task?<br>Is the procedure optimal?<br>Is the task correctly scheduled?<br>Is it to be entirely executed in an irradiated zone?<br>May some operators be moved to a distance?<br>Is number of operators justified?<br>Is the distribution of work optimised?<br>Can doses be spread between operators?<br>Are there special tools for reducing doses?<br>Is there an opportunity for remote control or robotics?<br>Can clothing be modified to facilitate the work?<br>Is there opportunity to improve ambient conditions (temperature, lighting)?<br>Is there an opportunity for radio communications?<br>Is there an opportunity for televisual surveillance?<br>Is there an opportunity for easier access?<br>Is handling equipment available?<br>Are there adequate superstructures? (scaffolding etc...)<br>Are there standing and procurement areas?<br>Are there procedures for packing equipment and packaging waste?<br>Are there procedures for removal of material?<br>… | | | |

Reference: (IAEA, 2002)

## *Appendix 4*

## EXAMPLES OF POST-JOB REVIEW FORMS

*Example of an ALARA Post-Job Review Form (NEA, 1997)*

<table>
<tr><th colspan="8">ALARA POST-JOB REVIEW FORM</th></tr>
<tr><td colspan="4">Authorizing Doc:</td><td>RWP:</td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Location</td></tr>
<tr><td colspan="8">Job Description</td></tr>
<tr><td colspan="2">Est. Man-hours</td><td>Act. Man-hours</td><td>% Difference</td><td>Est. man-Sv (Man-rem)</td><td>Act. man-Sv (Man-rem)</td><td>% Difference</td><td>Act. Effective Dose Rate</td></tr>
<tr><td colspan="2"></td><td></td><td></td><td></td><td></td><td></td><td></td></tr>
<tr><td colspan="8">Check one or more of the appropriate items listed below which may have contributed to higher than expected man-hour/man-Sv (man-rem) accumulation.</td></tr>
<tr><td></td><td colspan="7">1. Job scope changed or was extended.</td></tr>
<tr><td></td><td colspan="7">2. Job site radiological conditions changed.</td></tr>
<tr><td></td><td colspan="7">3. Encountered scheduling/work co-ordination difficulties.</td></tr>
<tr><td></td><td colspan="7">4. Work extended due to tool/equipment failure.</td></tr>
<tr><td></td><td colspan="7">5. Work extended due to wrong or unavailable parts/tools/equipment.</td></tr>
<tr><td></td><td colspan="7">6. Work extended due to unplanned job-site prep requirements.</td></tr>
<tr><td></td><td colspan="7">7. Work extended due to interruption/interference caused by other work activities.</td></tr>
<tr><td></td><td colspan="7">8. Inadequate compliance with radiological controls.</td></tr>
<tr><td></td><td colspan="7">9. Inadequate consideration of good ALARA practices.</td></tr>
<tr><td></td><td colspan="7">10. Radiation Work Permit inadequacies.</td></tr>
<tr><td></td><td colspan="7">11. Inadequate shielding.</td></tr>
<tr><td colspan="8">Comments:</td></tr>
<tr><td colspan="8">Suggestions for future improvements – lessons learned:</td></tr>
<tr><td colspan="6">ALARA Engineer:</td><td colspan="2">Date:</td></tr>
</table>

*Example of Mishaps Analysis Grid (NEA, 1997)*

**MISHAPS ANALYSIS GRID**

Identification of the job
Area: Material:

***1. MISHAPS ANALYSIS***

Mishaps Description:

Are there any radiation protection consequences? Immediate ☐
Likely in the future ☐

Are there modifications of working conditions (contamination, etc.)? Yes ☐ No ☐

**If yes:**

Impact on individual protection:

Impact on working time:

Work phases affected by the previous modifications:

Modification of one or more dose rates:

| Dose rate | Area | Dose rate | Area |
|---|---|---|---|
| | | | |

Work phases concerned by these dose rates:

Estimated impact of the mishaps on the level of exposure:

Actual impact of the mishaps on the level of exposure:

Identification of the job
Area: Material:

***2. ANALYSIS OF MISHAP CAUSES FOR POST-JOB REVIEW AND OF FEEDBACK***

1. INADEQUATE PROCEDURES
   - General processes ☐
   - Procedures to bring tools in the area ☐
   - Conditioning procedures ☐
   - Procedures for removal of tools ☐
   - Procedures for waste removal ☐
   - Protection procedures ☐
   - Individual protection ☐
   - Collective protection ☐
   - RP procedure for intervention ☐
   - Installation of service air/water ☐
   - Others ☐

2. INFORMATION, COMMUNICATION, TRAINING
   - Bad or insufficient training of workers ☐
   - Inadequate or ill-adapted training programmes:
     - Technical programme ☐
     - ALARA programme ☐
   - Mock-up training: Not planned ☐
     - Inadequate ☐
   - Defective communication ☐
   - Wrong verbal information or oversight ☐
   - Defective or partial technical information ☐
   - Defective maps ☐
   - Others ☐

**MISHAPS ANALYSIS GRID** (Cont'd)

3. WORK MANAGEMENT

4. WORK AREA PREPARATION AND WORKING CONDITIONS

| | | | | | |
|---|---|---|---|---|---|
| Defective pre-job analysis | | ☐ | Poor arrangement of working area | | ☐ |
| Poor distribution of tasks between workers | | ☐ | Inadequate cleanliness and poor arrangement of working area | | ☐ |
| Poor pre-job planning | | ☐ | Poor visibility/hearing | | ☐ |
| No follow-up of job planning | | ☐ | Deficient or unsuitable scaffoldings | | ☐ |
| Poor co-ordination | between workers | ☐ | Work constraints | working position | ☐ |
| | between teams | ☐ | | light | ☐ |
| | between firms | ☐ | | heat | ☐ |
| Insufficient availability of | workers | ☐ | Others | | ☐ |
| | tools | ☐ | | | |
| | machine | ☐ | | | |
| Unsuitable tools | | ☐ | | | |
| Others | | ☐ | | | |

5. INCIDENT DUE TO TOOLS

| | |
|---|---|
| Tool failure | ☐ |
| Lack of service air/water | ☐ |
| Inspection of tools failure | ☐ |
| Communication equipment failure | ☐ |
| Others | ☐ |

6. INCIDENT DUE TO HUMAN FACTORS

| | |
|---|---|
| Error due to non-application of rules or procedures | ☐ |
| Diagnostic error | ☐ |
| Non-adapted reaction | ☐ |
| Reaction time too slow | ☐ |
| Physical failure | ☐ |
| Others | ☐ |

Feedback on discussion with the team of causes of the mishaps, in order to identify and rank those at origin of the mishap.

*Example of a Post-Job Meeting Guide Sheet (NEA, 1997)*

| POST-JOB MEETING GUIDE SHEET | | | |
|---|---|---|---|
| To be discussed with the team leader of the job | | | |
| Identification of the job:<br>Area: Material:<br>Description of the job:<br>Meeting participants: | | | |
| | | Y | N |
| 1 | Were the required tools and materials available at the right time? | ☐ | ☐ |
| 2 | Was the zone ready for your task on your arrival? | ☐ | ☐ |
| 3 | Were the protection measures suitable for the job executed in this zone? | ☐ | ☐ |
| 4 | How much time did you have to prepare the job? Was this long enough? | ☐ | ☐ |
| 5 | Did other jobs interfere with your tasks? | ☐ | ☐ |
| 6 | Was the work location kept clean and orderly so as to facilitate your work? | ☐ | ☐ |
| 7 | Did the team members know their level of exposure? | ☐ | ☐ |
| 8 | Did you insist on this exposure being limited as much as possible? | ☐ | ☐ |
| 9 | Was the team aware of the dose objectives for the work? Was the team motivated? | ☐ | ☐ |
| 10 | Did you have co-ordination problems with other teams, other departments?<br>What problems did you encounter that could have resulted in higher doses? | ☐ | ☐ |
| 11 | Did you have difficulties in implementing the solutions to your problems? | ☐ | ☐ |
| 12 | Did you have administrative problems? | ☐ | ☐ |
| 13 | Was there a specific event which allowed you to reduce exposure? | ☐ | ☐ |
| 14 | Will you perform your task in the same way the next time? | ☐ | ☐ |
| 15 | Do you think that the process should be changed? | ☐ | ☐ |
| | Describe positive answers here: | | |

*Appendix 5*

## EXAMPLE OF A RADIOLOGICAL SUGGESTION FORM

<table>
<tr><th colspan="5">RADIOLOGICAL SUGGESTION FORM</th></tr>
<tr><td colspan="5">Section 1 – Originator</td></tr>
<tr><td>Name:</td><td>Dept:</td><td>Ext:</td><td>Mail:</td><td>Date:</td></tr>
<tr><td colspan="5">Area or procedure affected by this suggestion:</td></tr>
<tr><td colspan="5">Description of suggestion:</td></tr>
<tr><td colspan="5">Reason for suggestion:</td></tr>
<tr><td colspan="5">Section 2 – Suggestion Evaluation</td></tr>
<tr><td colspan="5">check one:<br>Radiological Improvement ☐<br>ALARA Improvement ☐ (If the suggestion is an ALARA Improvement, attach a cost benefit analysis)</td></tr>
<tr><td colspan="5">What is the estimated cost of the suggested improvement?</td></tr>
<tr><td colspan="5">Will the suggestion improve exposure reduction?</td></tr>
<tr><td colspan="5">What are the estimated benefits of the suggested improvement? (Attach additional information if necessary)</td></tr>
<tr><td colspan="5">The suggestion is not cost justifiable but should be implemented ☐</td></tr>
<tr><td colspan="5">The suggestion should not be implemented ☐</td></tr>
<tr><td colspan="2">Attachment ☐ Yes ☐ No</td><td colspan="3">The suggestion is cost justifiable and should be implemented ☐</td></tr>
<tr><td colspan="5">Recommend assignment to:</td></tr>
<tr><td colspan="5">Comments</td></tr>
<tr><td colspan="4">S-RE:</td><td>Date:</td></tr>
<tr><td colspan="5">Section 3 – Final Review/Approval</td></tr>
<tr><td colspan="2">The suggestion is APPROVED ☐</td><td colspan="2">The suggestion is NOT APPROVED ☐</td><td>CCT ☐</td></tr>
<tr><td colspan="4">Director of implementing department:</td><td>Date:</td></tr>
<tr><td colspan="5">Individual assigned for implementation:</td></tr>
<tr><td colspan="4">D-PRP:</td><td>Date:</td></tr>
</table>

Reference: (NEA, 1997)

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# Work Management to Optimise Occupational Radiological Protection at Nuclear Power Plants

Since 1992, the Information System on Occupational Exposure (ISOE) has provided a forum for radiological protection professionals from nuclear power utilities and national regulatory authorities worldwide to discuss, promote and co-ordinate international co-operative undertakings for the radiological protection of workers at nuclear power plants. The ISOE objective is to improve occupational exposure management at nuclear power plants by exchanging relevant information, data and experience on methods to optimise occupational radiological protection.

This report on work management provides practical guidance on the application of work management principles as a contribution to the optimisation of occupational radiological protection. It recognises that while work management is no longer a new concept, continued efforts are needed to ensure that good performance, outcomes and trends are maintained in the face of current and future challenges. The focus of this report is therefore on presenting the key aspects of work management that should be considered by management and workers to save time, doses and money, supported by updated practical examples from within the ISOE community.

ISOE is jointly sponsored by the OECD Nuclear Energy Agency and the International Atomic Energy Agency (IAEA).

ISOE Network: www.isoe-network.net

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