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# Occupational Radiological Protection Principles and Criteria for Designing New Nuclear Power Plants

NUCLEAR ENERGY AGENCY

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

## ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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## NUCLEAR ENERGY AGENCY

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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.

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# FOREWORD

The NEA has long been addressing the radiological protection of occupationally exposed workers. For example, in 1992, the NEA launched the International System on Occupational Exposure (ISOE) as a joint programme for technical information exchange, with the objective to provide a forum for radiological protection professionals from utilities and regulatory authorities to discuss and co-ordinate international co-operative undertakings for the radiological protection of nuclear power plant workers. This ongoing operational programme has proved successful in helping radiological protection experts at utilities and regulatory authorities to better manage occupational exposures at nuclear power plants. However, in accordance with its statute as a relatively independent technical exchange programme, ISOE does not address policy issues that might be of relevance to its membership or that could benefit from members' experience.

Given the interest of the NEA Committee on Radiation Protection and Public Health (CRPPH) in such policy issues, it agreed in 2006 to create an ad hoc Expert Group on Occupational Exposure (EGOE) to broadly explore policy and regulatory issues that could be usefully addressed by the CRPPH across many sectors, with a focus on the nuclear power industry, and to report back on possible follow-up. Additionally, recognising the significant operational experience residing within the ISOE programme and the potential benefits to both the CRPPH and ISOE of collaborative discussions in the area of occupational radiological protection policy, the NEA Secretariat was instructed to co-ordinate with the ISOE programme on its possible involvement in the EGOE. The ISOE Steering Group accepted the invitation to participate in the EGOE exercise.

The EGOE was tasked with identifying issues that could be usefully explored by the CRPPH. Possible areas that were considered include:

- Policy issues in occupational radiological protection identified by the Expert Group on the CRPPH Collective Opinion (for example, holistic approaches to risk management, maintenance and promotion of safety culture, issues related to decommissioning), or in the report of the ISOE Working Group on Operational Radiological Protection.
- Current experience in stakeholder involvement in occupational radiological protection, and its role in the management of occupational exposures.
- Policy, regulatory and operational lessons that can be drawn from a review of the regulatory assessment of "ALARA" (as low as reasonably achievable) programmes.

- The application of dose constraints in regulations and the impact on operational programmes.
- How the work of other CRPPH groups or initiatives contribute to the regulation and protection of occupationally exposed workers, for example in the areas of proposed International Commission on Radiological Protection (ICRP) environmental protection guidance, stakeholder involvement or best available technology.
- Issues concerning the implementation of the new ICRP recommendations.
- How ISOE operational experience can support the review and development of international guidance and advice for occupational radiological protection, such as the International Basic Safety Standards, or for new nuclear build.
- How the CRPPH can support the work under the International Action Plan for Occupational Radiation Exposure in a complementary and co-ordinated manner.

As a result of the EGOE's initial investigations and discussions, three areas were selected for the development of detailed case studies. The proposals, which were presented to and approved by the CRPPH in 2007, were:

1. Occupational radiological protection principles and criteria for designing new nuclear power plants (initial title: Criteria for new build).
2. ICRP implementation (working title: ICRP implementation – focus on "dose constraints").
3. Radiological protection policy and operational issues.

It was advised that these three case studies should be addressed in a step-by-step approach to best manage the workload. Following this recommendation, the Group prepared the present Case study No. 1, which was approved by the CRPPH in 2009.

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# List of acronyms

| | |
|---|---|
| ABWR | Advanced boiling water reactor |
| AGR | Advanced gas cooled reactor |
| ALARA | As low as reasonably achievable |
| ALARP | As low as reasonably practicable |
| ANSI | American National Standards Institute document |
| ARAN | Asia Region ALARA Network |
| ASME | American Society of Mechanical Engineers |
| BEG | British Energy Group |
| BOP | Balance of plant |
| BWR | Boiling water reactor |
| CANDU | Canadian light-water reactor |
| CETRAD | Co-ordination Action on Education and Training in Radiological protection and Radioactive Waste Management |
| CNS | Convention on Nuclear Safety |
| CUW | Reactor Water Clean-up Pump |
| DOE | Department of Energy |
| DP | Differential pressure |
| DPCs | Ducts, Pipes, Cables, and Conduits |
| EAN | European ALARA Network |
| EDF | Électricité de France |
| ENETRAP | European Network on Education and Training in Radiological protection |
| EPR | European Pressurised Reactor (sometimes called the Evolutionary Power Reactor) |
| ESOREX | European Study on Occupational Radiation Exposure |
| EUTERP | European Platform on Training and Education in Radiological protection |
| FSAR | Final Safety Analysis Report |
| HEPA | High-Efficiency Particulate Air |
| HVAC | Heating, Ventilation and Air-conditioning |
| IAEA | International Atomic Energy Agency |
| ICRP | International Commission for Radiological Protection |
| IEC | International Electrotechnical Commission |
| ILO | International Labor Organization |
| IRM | In-core radiation monitors |
| IRP | International Radiological protection Association |
| ISOE | Information System on Occupational Exposure |
| MSIV | Main Steam Isolation Valve |
| NCRP | National Council on Radiological protection and Measurement |
| NPP | Nuclear Power Plant |

| | |
|---|---|
| NRC | Nuclear Regulatory Commission |
| NSSS | Nuclear Steam Supply System |
| OECD | Organization for Economic Co-operation and Development |
| ORP | Occupational Radiological protection |
| PWR | Pressurized Water Reactor |
| RCA | Radiation Control Area |
| RECAN | Regional European and Central Asian ALARA Network |
| RHR | Residual Heat Removal |
| RPM | Radiological protection Manager |
| SRV | Safety Relief Valve |
| SSC | Structures, Systems and Components |
| TIP | Transversing In-core Probes |
| TMI | Three Mile Island |
| VVER | Water-cooled Water-Moderated Power Reactor (Russian version of the PWR) |
| WENRA | Western European Nuclear Regulators' Association |

# Executive summary

## Introduction

This case study introduces a policy and technical framework that may be used when formulating technical assistance and guidance for use by the executive management of nuclear power plants (NPP), designers, manufacturers, contractors and by authorities responsible for regulating occupational radiation exposure. This material is aimed at assisting the design and license assessment of new nuclear power plants (i.e. 3rd generation or beyond), and is based on experience and lessons learnt from the existing fleet of reactors. Although not primarily aimed at the needs of countries newly embarking with nuclear power, this material can also provide valuable input on occupational radiological protection (ORP) issues for the implementation of new nuclear energy programmes.

The future reactors are based on evolution of PWRs, BWRs, CANDU and VVER reactor types. Thus the focus is to shed light on the experience of these types of technology.

## Objects of the study

This case study focuses on the strategic areas of ORP as practiced in the nuclear power sector in order to bring clear benefit to future generations of nuclear reactors. Particularly, it is focused on:

- Description of ORP principles for use by new NPPs.
- Evaluation of potential implications of newly available and emerging technologies on ORP aspects of new NPP designs.
- Implementation of ORP experience, in particular:
  - Lessons from the operation of 1st and 2nd generation reactors that can be used for new NPP designs.
  - Experience with the replacement of various components.
  - ORP experience relevant to decommissioning.

## Motivation and background

The global need of electricity continues to increase and numerous new NPPs are being planned or erected in the member states of the OECD in the near future.

Most of these new NPPs will be NPPs of the 3rd generation and designed for operating as long as 80 years.

That implies:

- ORP is required for two or more generations of NPP workers.
- New technical developments will emerge and unforeseen maintenance and repair activities will occur.

Many international documents on ORP in NPPs are available from international institutions or national initiatives. This case study includes those provisions for ORP principles developed from experience with existing NPPs that can serve as a practicable tool for the design phase of new NPPs.

Experience from the past decades shows that ORP was very successful in reducing the radiation doses received by workers during operation and maintenance/refuelling phases in NPPs of the 1st and 2nd generations.

One of the lessons learnt during these decades is that a substantial amount of exposure resulted from lack of attention for ORP concerns in NPP designs. Factors such as nuclear safety and operational availability dominated during the design and construction phases of the NPP, whereas ORP aspects were addressed to a lesser extent. Later, after significant numbers of NPPs had begun operation and undergone maintenance and refueling outages, ORP found itself faced with a *fait accompli* and was forced to deal with exposure situations that resulted from initial architectural/engineering and design shortcomings.

There is a significant potential to avoid radiation doses, as well as long-term maintenance costs, if ORP considerations are embedded at the architectural design and construction phase (e.g. integrated ladders/stairs instead of mobile scaffolds, easily accessible cable tunnels, in-duct laid pipelines etc). Furthermore, the productivity of an NPP can be improved if ORP, as well as other risks to workers, are considered early in the design phase (e.g. if correctly designed and planned, some maintenance operations could be performed during reactor operations or with a reduced shutdown time; the exchange of whole components instead of repairing defect parts *in situ* etc.). Finally, radiation doses of workers can be substantially avoided when future exposure situations in all phases of a reactor life-cycle are anticipated and proactive measures taken.

## Guiding principles

Good management of ORP is sustainable, economic and confidence-building. Several guiding principles that should be considered as crucial for the successful integration of ORP in design of new NPPs are as follows:

- Proactive implementation of lessons learnt.

  Crucial decisions affecting future radiation exposure of workers, and also long-term expenses for maintenance, outages and modifications are made in the design phase of a new NPP. Both radiation doses and costs can be reduced over the life-cycle of the new NPP when the practical experience from decades of ORP in existing NPPs is taken into account at an early stage, i.e. included already in the architectural design. Furthermore, it is wise to anticipate potential occupational exposure for the full NPP life cycle (i.e. from operation to decommissioning) and take optimisation measures in advance.

- Balance of risks and allocation of resources.

  Radiation exposure is not the only risk to be considered in designing new NPP. The allocation of resources for occupational health and safety at the design phase should be based on a rational balance aimed to optimise protection against all risks to workers.

- Effective communication in optimising design.

  Licensing requirements for safety and protection of public and environment may require technical and organisational measures that increase radiation exposure of workers. The designer and operator must understand regulatory requirements and their interpretation for surveillance, inspection, and other activities during the plant's operating phase. Having that clear understanding enables the designer to develop means and use design elements that reduce radiation exposures. This requires close co-operation between regulators, designers and operators, as well as transparent and active consultation with other stakeholders.

- Publicly recognisable effective ORP.

  The concept of ORP should be forward looking, addressing all phases of the life-cycle of the NPP and supported by the full pool of operational experience. This demonstrates effective management and creates trust in the operation of the NPP. Management must always be aware that if the handling of ORP appears negligent in the public's or regulator's view, then the trust in the nuclear safety and in the reliability of the management is put at risk. This jeopardises not only the operational availability of the NPP but also the nuclear technology as a whole.

## The content of the study

This case study is structured into chapters, as to clearly address the topics listed in the scope. At the beginning of each chapter, the corresponding key messages are given, as in the following presentation of these chapters:

### *Chapter 1.*

### *Occupational radiological protection principles at the design stage of nuclear power plants*

- International guidance and compliance with standardisation.
- National guidance and role of regulatory authorities.
- Implementation of ORP philosophy at the design stage: Requirement for a structured organisation, such as an ALARA Design Review Committee.

### *Chapter 2.* *Lessons learnt, knowledge management, education and training*

Operating experience should be utilised to identify opportunities for dose reduction as part of design.

- Lessons learnt, taking into account the experience and feedback from designing, operating, maintenance and dismantling of existing NPPs.
- Collection and exchange of data, networking, data analysis, good practice.
- Knowledge management and its organisation as early as during the design stage, as to be effective during the whole life cycle of the plant.
- Need for well trained, skilled and knowledgeable persons in ORP during the design stage and during the full life cycle of the plant.

### *Chapter 3.* *Integrating occupational radiological protection criteria during the design phase*

- Screening process for compliance of proposed design with existing ORP criteria.
- ALARA design check-list.
- Example of EPR.
- Evaluation of newly available and emerging techniques in ORP aspects.

### *Chapter 4.* *Evaluation and integration of occupational radiological protection cost in the design process*

- Most significant ORP costs to be evaluated.
- Decision making criteria.

The list of references, including international guides and networks websites is provided at the end of the document.

## Conclusions

The objective of this case study is to analyse existing ORP experience in currently operating nuclear power plants in order to assess how ORP should best be applied in future NPPs. The purpose of this document is to assist in the assessment of ORP aspects of design and license applications for new nuclear power plants by providing a policy and technical framework that can be used for making judgements. It is primarily, but not exclusively, directed to designers, manufacturers, contractors and authorities responsible for regulating occupational radiation exposure. It identifies the following major issues that need to be considered and incorporated into design:

- Basic ORP principles – justification, optimisation and dose limitation to be maintained through the expected full life-cycle, in order to address international and national guidance and regulations.

- Optimisation should consider not only potential health risks from ionising radiation, but also other potential risks for the workers' health in order to allocate resources in a well balanced way so that the best worker protection is achieved.

- Organisation of training and knowledge management to assure the availability of highly qualified personnel and adequate design-basis documentation over the full lifetime of the facility, from design to decommissioning.

- Active networking in support of information, experience and data exchange and assessment to maintain sustainable implementation of good practice, and ensure an effective traceability and use of lessons learnt.

- Need for the integration of ORP principles and criteria into all components and future operations in order to save time, money and exposure over the lifetime of the facility.

All the above issues are further elaborated in this report, providing guidance and technical information when needed.

# Introduction and scope

The licensing of new nuclear power facilities poses many new challenges to national regulatory organisations. Fortunately, the situation is that most of these new nuclear power plants (NPP) are designed according to broadly standardised criteria. Such standardisation can help to share experience and knowledge at the international level, and thus help to optimise the resources of the countries faced with the review of new reactor power plant designs in the near future. After building approval, the Regulatory body or another relevant governmental body supervises the implementation of the plant project in detail from a regulatory context. The various stages of the construction of an NPP are managed on the basis of the nationally and internationally adopted approaches to help assure that, for each stage of construction, factors affecting safety and regulations have been given adequate attention. Among other conditions to be met prior to the granting of licenses for site preparation, construction, operation or even decommissioning of a new NPP, are those related to occupational radiological protection (ORP).

The results of this case study will provide policy and technical experience for use by executive management of NPPs, designers, manufacturers and contractors in implementing ORP *a priori* as part of the design, and by nuclear regulatory authorities in assessing ORP aspect of new design. This material is aimed at assisting the design and license assessment of new nuclear power plants (*i.e.* 3rd generation or beyond), and is based on experience and lessons learnt from the existing fleet of reactors. Although not primarily aimed at the needs of countries embarking with nuclear power, this study can also provide valuable input on ORP issues for the implementation of new nuclear energy programmes.

The future reactors are generally based on evolution of PWRs, BWRs, CANDU and VVER reactor types. Thus the focus is to shed light on the experience of these types of technology.

## Background

The global need for electricity continues to increase, and numerous new NPPs are being planned for the near future or are currently being built in the OECD member countries. Most of these new NPPs will be of the 3rd generation and designed to operate as long as 80 years.

Ramifications include the following:

- ORP is required for the full life cycle of the facility, including decommissioning, and with recognition that substantive equipment replacement may occur about every 20-30 years.

- Transfer of knowledge between two or more generations of NPP workers is needed, and the same is true for the regulatory agency staff.
- New technical developments will emerge and unforeseen maintenance and repair activities will arise which will impact ORP.

In addition, preservation and archiving of ORP and related design and licensing data will need to be addressed from the beginning.

Many relevant documents addressing ORP in NPPs are available from international institutions and from national initiatives.

One of the lessons learnt during from past decades is that some worker exposures were due to a lack of sufficient attention in NPP designs regarding the avoidance or reduction of exposure. Factors such as nuclear safety and operational availability dominated during the design and construction phases, whereas ORP aspects were addressed to a lesser extent. Later, as significant numbers of NPPs began operation and were undergoing maintenance, refuelling outages, modification and even decommissioning, ORP found itself faced with a *fait accompli* and was forced to deal with exposure situations that resulted from initial architectural and design shortcomings.

Another factor leading to possible later exposures that may have been avoidable is a perceived lack of sufficient co-operation among and integration of information available from architect-engineering firms, utility design engineering groups, utility plant operating, staff or their consultants, and regulatory agency staff.

Despite the obstacles to ORP due to these factors, the experiences from past decades shows that ORP has been very successful in reducing the radiation doses received by workers during operation, maintenance and refuelling phases in NPPs of the 1st and 2nd generations. Nonetheless, there is a significant potential to avoid or reduce radiation doses in new plants, as well as long-term maintenance costs, if ORP considerations over the life cycle of the facility are addressed through multidisciplinary approach and embedded at the architectural design and construction phase. Furthermore, the productivity of an NPP can be improved if ORP, as well as other risks to workers, are considered early in the design phase.

The case study includes those provisions for ORP principles in existing NPPs that serve as a practicable tool for the design of new NPPs. It also identifies policy and technical aspects, and draws lessons from available operating experience to proactively include optimisation of ORP at the design phase of NPPs.

## Guiding principles for integration of ORP in the design phase

Management of ORP is always a complex issue, and good management should be sustainable, economic and confidence-building.

For example, the optimisation principles of ICRP state that the likelihood of incurring exposures, the number of people exposed and the level of their individual doses should all be kept as low as reasonably achievable (ALARA), taking into account social and economic factors. The target level of protection shall be found by calculating its monetary costs and considering non-monetary factors whose relevance is not a matter of quantifiable costs but of value judgements. Thus, the optimisation process as part of design should be committed to working on design features that can reduce occupational dose as well as the potential radiation burden to the public and environment to the lowest reasonably achievable level.

Understanding this, it is suggested that the optimal allocation of resources for occupational health and safety should be based on a rational balance between all workplace risks in the context of total risk management. The result of such an approach will thus not necessarily be the option with the lowest doses, but should result in the lowest reasonably achievable risk to workers.

There are several guiding principles identified that are considered to be crucial for the successful integration of ORP in design for new NPPs:

- Co-operation, communication and multidisciplinary approach in optimising design.

  Designers and operators need to understand implications of design and operational features on ORP. They shall also understand regulatory requirements and how those requirements are interpreted for surveillance, inspection, and other activities during the plant operating phase. Regulators need to understand technical constraints in facility construction and operations to enable those interpretations to be informed and reasonable. These clear understandings will help to enable the designer to develop means and use design elements that help assure that radiation exposures are ALARA. This requires close co-operation between regulators, designers and operators. It also facilitates the regulators' role in transparent, open and active consultation with stakeholders.

- Multi-disciplinary communications within and among organisations.

  In addition to the above described communications between the design, operator and regulatory organisations, there is also the importance of multi-disciplinary communications within and among those organisations. The integration of information from, for example, radiological engineers, ventilations experts, chemists, and in-service inspection personnel is of great importance.

- Proactive implementation of lessons learnt.

  Crucial decisions affecting future radiation exposure of workers and also long-term expenses for maintenance, outages and modifications are made in the design phase of a new NPP. Both radiation doses and costs can be reduced over the life-cycle of the new NPP when the practical experience from decades of ORP in existing NPPs is included in the architectural design at an early stage. It is furthermore wise to anticipate potential occupational exposure for the full NPP life cycle (i.e. from operation to decommissioning) and take optimisation measures in advance. An integrated, proactive initial design may be less costly over time than having to make multiple modifications to a less-than-comprehensive initial design.

- Balance of risks and allocation of resources.

  Radiation exposure is not the only risk to be considered in designing new NPPs. The allocation of resources for occupational health and safety at the design phase should be based on a rational balance aimed at optimising protection against all risks to workers.

- Effective ORP.

  The concept of ORP should be multidisciplinary and forward looking, addressing all phases of the life-cycle of the NPP as radiation safety experts provide input into the facility design. This input should consider all available operational experience relevant to the reactor type being considered for construction. The designer and operator need to internalise and communicate a sense of ownership of the adequacy of the initial design for ORP and the ability to operate the plant safely and reliably, with the lowest reasonably achievable risk to workers. As supplemental benefit, such a communicated commitment helps to build a level of trust among regulatory staff that workers health and safety will be ensured by the operating staff.

## Scope

This case study focuses on the strategic areas of ORP in order to bring clear benefit to future generations of nuclear reactor workers and its management. Particularly, it is focused on:

- Description of ORP principles for new NPPs.
- Evaluation of potential implications of newly available and emerging technologies on ORP aspects of new NPP designs.
- Implementation of ORP experience, in particular:
  - Lessons from the operation of 1st and 2nd generation reactors that can be used for new NPP designs.
  - Experience with the replacement of various components.
  - ORP experience relevant to decommissioning.
- Providing references to existing technical literature.

The scope of the case study covers issues that affect the design of future NPPs from the viewpoint of long-term occupational exposure. The individual subjects shall address what is needed to be included in the design phase from the point of ORP. The range of involvement of designers and manufacturers in ORP is, in general, very broad, from suppliers of large reactor components to suppliers of radiation control and protection systems. In order to cover broad issues as mentioned here, the case study is structured into chapters, as to clearly address the topics listed in the scope. At the beginning of each chapter, the corresponding key messages are given, as in the following presentation of these chapters.

### Chapter 1.
### Occupational radiological protection principles at the design stage of nuclear power plants

- International guidance and compliance with standardisation.
- National guidance and role of regulatory authorities.
- Implementation of ORP philosophy at the design stage: requirement for a structured organisation, such as an ALARA Design Review Committee.

### Chapter 2.
### Lessons learnt, knowledge management, education and training

Operating experience should be utilised in the design phase in order to identify opportunities for dose reductions; in particular by means of:

- Lessons learnt, taking into account the experience and feedback from designing, operating, maintenance and dismantling of existing NPPs.
- Collection and exchange of data, networking, data analysis, good practice.
- Knowledge management and its organisation starting with the design stage, and lasting over the whole life cycle of the plant.
- Well trained, skilled and knowledgeable persons in ORP during the design stage and during the full life cycle of the plant.

### Chapter 3.
### Integrating occupational radiological protection criteria during the design phase

- Screening process for compliance of proposed design with existing ORP criteria.
- ALARA design check-list.
- Example of EPR.
- Evaluation of newly available and emerging techniques in ORP aspects.

### Chapter 4.
### Evaluation and integration of occupational radiological protection cost in the design process

- Most significant ORP costs to be evaluated.
- Decision making criteria.

# 1. Occupational radiological protection principles at the design stage of nuclear power plants

### Key messages

Three basic ORP principles, justification, optimisation and dose limitation need to be followed during the design process of an NPP, and available international guidance shall be used in their implementations. Particularly, the design effort shall be aimed at optimising protection against all risks to workers, and to ensure a well balanced allocation of resources for occupational health and safety once the NPP begins operation. During design, relevant available international guidance (*e.g.* ICRP) and existing international conventions shall be taken into account (nuclear safety conventions, conventions addressing radioactive waste management, ILO conventions on radiological protection etc.). Within the framework of these general ORP principles and available international guidance, and following all existing national regulations, existing experience and local conditions and specificities should support design efforts.

## 1.1 International guidance

### *Recommendations from the International Commission on Radiological Protection*

The International Commission on Radiological Protection (ICRP) [1] periodically publishes the principles of radiological protection, which are generally implemented in regulation and in practice around the world. The most recent of these recommendations, publication ICRP Publication 103 [2], recalls the Commission's three basic principles, which are to be applied for all radiological protection, including occupational radiological protection:

- 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 ALARA, 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 dose limits.

These principles, to be applied during plant operation, should however be taken into account already at the design stage of new plants.

Notably, in order to apply the principle of optimisation of radiological protection, it has to be recalled that from the ICRP point of view: "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".

It should be noted that, even though the statements defined by the ICRP on radiological protection are only recommendations, these statements are often included in regulations on radiological protection.

### *International conventions*

Nuclear power has several inherently international aspects that need national regulations and international agreements in order to ensure appropriate management of risks. In this regard, international conventions have been developed in order to facilitate and harmonise national understanding of these international aspects. Many international organisations, in particular the IAEA, EC and ILO, have developed international conventions and binding directives to facilitate this understanding.

The main international conventions which can be mentioned when addressing the issue of ORP at the design stage of facilities are:

- Convention on Nuclear Safety (CNS).
- Joint Convention on the Safety of Spent Fuel Management and on the Safety of Radioactive Waste Management.
- ILO Convention on ORP [3].
- European Basic Safety Standards Directive [4].
- International Basic Safety Standards for Protection against Ionising Radiation [5].

These conventions are incentive instruments for contracted parties. They should also be respected in an early stage of the plant design. For example, one of the objectives of CNS is to establish and maintain effective defences in nuclear installations against potential radiological hazards in order to protect individuals, society and the environment from harmful effects of ionising radiation from such installations.

Related to radiological protection, each contracting party shall take the appropriate steps to ensure that in all operational states the radiation exposure to the workers and the public and the environment caused by a nuclear installation shall be kept ALARA, and that no individual shall be exposed to radiation doses which exceed prescribed dose limits.

Regarding design and construction, as defined by CNS, each contracting party shall take the appropriate steps to ensure that:

- The design and construction of a nuclear installation provides for several reliable levels and methods of protection (defence-in-depth) against the release of radioactive materials, with a view to preventing the occurrence of accidents and to mitigating their radiological consequences should they occur.

- The technologies incorporated in the design and construction are proven by experience or qualified by testing or analysis.
- The design allows for reliable, stable and easily manageable operation, with specific consideration of human factors and the man-machine interface.

As per the Joint Convention, the contracting parties recognise that the operation of nuclear reactors generates spent fuel and radioactive waste, and thus the same safety objectives shall apply both to spent fuel and radioactive waste management. Design and constructions of facilities, as defined by the Joint Convention, shall ensure that:

- Design and construction of a spent fuel and radioactive waste management facilities provide for suitable measures to limit possible radiological impacts on individuals, society and the environment, including those from discharges or uncontrolled releases.
- At the design stage, conceptual plans and as necessary technical provisions for the decommissioning of spent fuel and radioactive waste management facilities are taken into account

## 1.2 Occupational radiological protection philosophy at the design stage

Radiation exposure should be considered as one risk among others for workers in NPPs. For instance, hazardous and stressful work conditions like scaffolding, with the risk of falling, work under high temperature, handling of chemo-toxic substances, use of breathing and anti-contamination equipment that may cause additional heat stress, may lead to an increased risk of incident/accident or even to adverse health effects. These as well as other work conditions should be considered when defining the appropriate level of radiological protection. At the design stage, the general philosophy should be based on a rational balance aimed to optimise protection against all risks to workers, as to ensure a well balanced allocation of resources for occupational health and safety.

Moreover, there is a significant potential to avoid radiation doses and long-term maintenance costs, as well as facilitate decommissioning if ORP considerations are embedded at the architectural design and construction phase (*e.g.* integrated ladders/stairs instead of mobile scaffolds, easily accessible cable tunnels, in-duct laid pipelines etc.). The practical experience from decades of ORP in existing NPPs is of the utmost importance, and lessons learnt from operating NPPs are the main assets to anticipate potential occupational exposure for the full NPP life cycle (*i.e.* from operation to decommissioning) and taking optimisation measures in advance.

These general considerations emphasise the importance of anticipating exposure situations in all phases of a reactor life-cycle and take corresponding proactive measures.

In order to implement this methodology, a multidisciplinary approach involving all relevant parties should be adopted. The roles of these parties are further elaborated below.

## 1.3 National guidance and role of regulatory authorities

National regulations and regulatory guidance for the design of nuclear facilities will reflect not only national requirements, but also international consensus and guidance regarding safety and radiological protection.

From a general point of view, national regulations and regulatory guidance should:

- Maintain public confidence that there is a credible independent technical regulator.
- Allow for public access to information on criteria used to make regulatory decisions; including those on burden reduction activities.
- Demonstrate an integration and coherence of regulation across all governmental agencies (nationally and where feasible, internationally).
- Be written for effectiveness and efficiency for both the regulator and the licensee.
- Be risk-informed and performance-based, to maintain a proportionality between risk significance and regulatory burden.
- Include processes for regulator/licensees dialogue to help to maintain regulatory accountability for appropriate regulatory focus on worker and public health and safety.
- To allow processes that allow for simple changes to be made without intensive programmatic activity.
- Allow for generic action by individual licensees or groups of licensees, rather than repetitive actions or submission by multiple individual licensees.
- Provide for periodic review of existing regulations and regulatory guidance, to ensure a continued maintenance of focus on safety, public confidence, and efficiency.

### *Review of the design process from the regulatory point of view*

One approach to assuring that all lessons and experience have been properly assessed and appropriately implemented is to use a pre-established process of assessment. This would include such regulatory guidance as what types of facilities to study (*e.g.* sister plants, previous generation plants, other similar facilities etc.), where to search for relevant good practice (*e.g.* regulatory authority databases, international data and information exchange systems, industrial/trade organisation experience and databases etc.), experience in establishing protection option selection criteria (*e.g.* dose constraints, alpha values, risk assessment approaches etc.), and other review process elements.

Ideally, the regulatory authority responsible for the approval of new NPPs should ensure that the experience review processes proposed by the license applicant have been properly and thoroughly carried out through a regulatory requirement. In this respect, for the purposes of consistency, thoroughness and fairness, clear and comprehensive guidance should be provided, generally in the form of a regulatory guidance document. However, irrespective of their particular regulatory requirements, designers and manufacturers are encouraged to include these processes as integral steps in their plant design in order to aid in ensuring that doses to workers are ALARA.

The regulatory guidance document will form a preliminary check-list not only for the manufacturer but also for approval process within the regulatory authority. Dose estimation to workers for routine and maintenance operations should be reviewed for completeness and verified, including external and internal exposures. Where modifications have been made in the design, dose savings should be detailed, including what options were examined. Where appropriate, a cost benefit analysis should be provided, especially when the doses from the chosen design exceed that of other, more costly designs. There should also be a documented review of current operating experience, such as that provided through the ISOE programme [6], indicating how relevant topics were addressed, *i.e.* found beneficial and accepted or rejected based on sound rationale.

Regulatory authorities should review the application for thoroughness and reasonableness. Ideally the reviewing authorities should have sufficient ORP experience in NPP operation to judge if the analysis, resultant design and lessons learnt have been appropriately implemented.

### *Evaluation of the integration of ORP into the design process*

In evaluating ORP integration in design, the regulator will, in general, focus on two major areas:

- That the applicant has a process in place to ensure that those elements of the design having direct radiation safety implications will consider dose optimisation in the design process.
- That the applicant has a process to obtain and use input from radiation safety professionals in the design development process.

Such an evaluation may include the scheduling of focused discussions between regulatory, agency and utility (and architect-engineering) personnel regarding the use of dose-optimisation techniques and the application of lessons learnt from NPPs currently in operation.

### *Source-term identification*

The characterisation of source terms is essential to the design of shielding and processes intended to protect workers. Much international literature has been developed in this area (see Appendix 1). Several of the most important aspects relating to source term characterisation, that will help guide regulatory authorities in their assessment of license applications and licensees in preparing them, are provided here:

- There should be an active process to identify all potential radiation sources that could cause workers either external or internal (due to airborne or surface contamination) exposures.
- Source term estimation should be as realistic as possible, but where there is doubt, a conservative value should be applied within reason.
- During plant operation and maintenance, integrated measurement systems should allow the identification of source terms of radiation (*i.e.* external gamma and neutron, airborne beta and gamma) or radioactive materials, (*i.e.* fission products, tritium in piping systems and others). And NPP designers should include these systems in their designs.

### *Occupational exposure assessment and ALARA considerations*

The design of an NPP will have numerous source terms and activities that will lead to occupational exposures. The licensee should implement, and the regulatory authority should assess, a documented process to develop thorough estimations of occupational doses for different work groups. Operational, routine maintenance, and special maintenance work should be reviewed, and dose estimates made based preferably upon actual measurements of radiation levels in existing plants of similar design, if necessary supplemented by computational modelling. If the licensee, or regulatory organisation, has fixed an individual dose constraint, it should be demonstrated that the assessed doses for planned operations remain below this constraint.

Experience from operating NPPs, in particular the dose consequences that could arise from design modifications from existing plants, should be actively investigated and provided to regulatory authorities as an integral part of the licensee application. If doses are predicted to increase as a result of the new design, means to reduce that dose should be explored and if found feasible and ALARA, then also included in the design.

The dose assessment process should include ALARA reviews (see Chapter 4), to allow the tracking of possible choices to achieving ALARA exposures, and the rationale for choices made. Where the national authority recommends ‘alpha values’ (reference cost per unit of dose saved), or where industrial practice has established operational alpha values, these should be used to guide judgement regarding dose-saving design aspects during the design process. When assessing design options, alternatives should be explored and reasons provided why one choice was made over another. License applications should make clear the most significant aspects of these assessments and choices, and should demonstrate that the predicted residual doses are expected to be ALARA. This assessment should of course consider exposures due to all types of work, including normal operation, routine maintenance and refuelling activities.

Within the document presenting actions to reduce exposures, it will be important that the license application includes a shielding assessment, as well as the associated structural plans of the facility.

### *Risk assessment*

In identifying the radiological risks that a proposed plant may create, it will be important that the license applicant include clear consideration of operational aspects, and provide clear approaches to the management of these risks. The assessment should thus include:

- Design layout and workflow.
- Radiation safety procedures – which would address ALARA issues.
- Staffing requirements.

Design considerations should also include adequate mitigation measures to limit exposure from unforeseen mishaps, *i.e.* added capacity of ventilation systems to remove any accidental releases of airborne contaminants, moveable shielding for maintenance work etc.

## 1.4 Role of designers and operators

In designing new plants, the first duty of designers and operators is, of course, to ensure worker, public and environmental safety, and to comply with regulations. For the particular aspect of occupational radiological protection, they carry the main responsibility for the implementation of the optimisation of protection throughout the design process. As a consequence, they are responsible for setting up an appropriate organisation to assure the integration of ORP criteria at the various stages of the design process, starting at its very beginning (see Chapter 3).

Designer considerations include not only technical issues but also economic constraints. These constraints are expressed in the principle of radiological protection optimisation: to reduce individual and collective exposure to ALARA levels taking into account social and economic factors.

Another emerging consideration of the designers should be the increasing lifetime of the future NPPs, as long as 80 years, entailing at least the three following issues:

- The importance of organising the management of knowledge, taking into account the required tuning to significant changing information technologies during almost one century (as information on technical features is essential during the dismantling phase).
- The training of two or more generations of workers and the careful recording of practical experience from everyday work.
- The need for establishment of appropriate record keeping systems enabling experience exchange in maintenance operations during the extended lifetime.

Designers and operators should define an efficient decision making methodology, aiming to integrate consideration of the long-term approach, as well as technical and economical issues. Multidisciplinary teams able to determine the best technical and economical options, taking into account operation and maintenance tasks, as well as anticipating dismantling, should be involved very early, and included at the management level.

The ALARA Design Review Committee is one of several approaches to address this general topic for ORP issues. Its purpose is to carry out ongoing independent design reviews of the nuclear unit, with the objective to verify that the NPP design assures that occupational exposures will be ALARA and will be in compliance with applicable ORP criteria, regulations and engineering standards (see details in Chapter 4).

# 2. Lessons learnt, knowledge management, education and training

## Key messages

Operating experience shall be utilised in order to identify opportunities for dose reductions as part of design. One such opportunity is to analyse dose trends in order to fix dose objectives for new NPPs and to identify good practice by comparing NPPs of the same design. This will lead to the identification of good practices that already have been incorporated in existing facilities, and will help to identify what could be expected to be achieved in the future, particularly how much exposure the good practice may be able to save. Available ORP information from existing professional networks (*e.g.* ISOE, ALARA networks) shall be exchanged and collected in determining good/bad practices in the ORP field. In this determination, relevant examples and analysis of dose trends shall be used in setting protection objectives to help guide the design process. It is also important to start planning at the very beginning of the plant design, as some specific design features might be necessary to support the knowledge management process during the future plant operation. In this regard, knowledge management structures, processes and procedures that are designed into future plants should be based on knowledge management experience from currently operating plants. This past ORP knowledge is essential to guide new plant design. In addition, the need for well trained, skilled and knowledgeable persons in ORP, both during the design stage and during the life cycle of the plant, is well recognised as being essential to the accomplishment of ORP goals during the future operation of the plant.

## 2.1 Lessons learnt from feed-back experience analysis

### *Analysis of existing data*

In order to identify good practice, regulators and operators alike should review occupational doses at NPPs of similar design, in particular looking for trends over the lifetime of the reactor, in terms of collective dose for all station personnel, by separate work groups, (*i.e.* maintenance, operations, fuel handling etc.) as well as in terms of individual dose distribution.

The analysis of dose trend can both be used to set dose objectives for new NPPs (in terms of collective and/or mean individual dose), as well as to identify good practices by comparing NPPs of the same design to check if any individual reactor stands out either due to higher or lower doses than normal. In assessing such trends, it is important to understand, in detail, the on-site activities that have resulted in exposures increasing or decreasing. Only from this level of understanding can good and, just as importantly, bad practice be identified.

Any recurring high exposure jobs (see Table 1) should also be reviewed by identifying the source of the dose, the dose magnitude and the dose rate. For new plants, the need for such high dose jobs should be eliminated if possible. If elimination is not possible or remote, less dose penalising options, such as arranging for lesser radiation fields, or managing the work in a shorter time period, should be explored and implemented so that exposures are ALARA. Table 1 below shows an example of the "top ten" high exposure jobs in NPPs [7].

Table 1. **Typical high dose jobs at light-water reactors**

| **"Top ten" high dose jobs** | |
|---|---|
| Control rod drive maintenance[1]<br>In-core radiation monitors (IRM)<br>In-service inspection<br>Main steam isolation valve maintenance (MSIV)<br>Pressuriser valve maintenance<br>Reactor water clean-up pump maintenance (CUW) | Recirculation pump maintenance and replacement<br>Residual heat removal system valve maintenance (RHR)<br>Safety relief valve maintenance (SRV)<br>Calibration and repair of transversing in-core probes (TIP) |
| **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 | Reactor water cleanup heat exchanger maintenance<br>Refuelling<br>Scaffold installation and removal<br>Snubber inspection and repair<br>Steam generator maintenance<br>Steam generator replacement<br>Power range monitors (PRM)<br>Start-up or source-range monitors (SRM)<br>Torus inspection and repair<br>Weld overlay job of recirculation system piping |

Source: NEA (2009).

### *Good practices*

A good practice is a programme, process, strategy or activity that:

- Has been shown to be effective in the control and optimisation of occupational radiation exposure.
- Has been implemented, maintained, and evaluated.
- Is based on current information.
- Is transferable and of value to other NPPs of similar design [8].

Where a good practice has resulted in a change to an already operating NPP, the proponent of a new design should identify good practices that can be incorporated into new designs. This includes improvements implemented by the operators of previous generations. There should be an active and documented process indicating the good practices that have been incorporated and what they

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[1] Some plants move/conduct some of this work off-site by a contractor.

are expected to achieve. This can be supplemented with historical information concerning from where the good practice was taken, and how much exposure it was able to save.

New technologies should also have been reviewed (*i.e.* remote monitoring using wireless telemetry, video cameras) and incorporated where possible (see Chapter 4).

### *Data collection/Networks*

In data collection and networking, the following issues need to be considered:

- The feedback and experience from a given type of NPP, which could be shared between concerned operators as well as the designer, in order to efficiently and widely share improvements occurring during the life cycle of these NPPs.
- Feedback and experience relating to the general improvement (national and/or international level) in design, operation and dismantling of NPPs.

Some examples of existing national/international networks of professsionals where information related to ORP and/or improvement for new NPP design can be exchanged and collected are given below. According to the number of new reactors estimated to be built over the next decade, it should be envisaged to create within these networks, dedicated platforms or areas to discuss the issue of ORP at the design stage of NPPs and exchange information on good and bad practices in this specific field.

#### *ISOE*

The ISOE is the world's most comprehensive source of experience and information for occupational exposure management at NPPs, and offers its members a variety of resources for occupational exposure management, including:

- A global network of radiological protection professionals from nuclear electricity utilities and national regulatory authorities.
- The world's largest database on occupational exposure from NPPs.
- Detailed studies and analyses on current issues in operational radiological protection.
- Annual analysis of dose trends and an overview of current ISOE developments.
- A forum for discussing occupational exposure management issues through ISOE international and regional symposia.
- Support through responses to special requests and the organisation of voluntary benchmarking visits for the sharing of good practice in occupational radiological protection.
- The ISOE Network [6]: a "one-stop" information exchange website for ISOE members, providing access to ISOE products, resources, and on-line user forums.

The ISOE database on occupational exposure data for workers at NPPs 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. This database contains occupational exposure data from many years of collective experience in the nuclear industry. It can be used to analyse collective dose trends according to the type of reactors, and by rector design group. It also allows the benchmarking of exposures from critical jobs against exposures and experience at other plants around the world. All members of the ISOE system can access this database (with different data access privileges between utilities and authorities: authorities do not have access to the full database) [9-10].

### *ALARA networks*

- European ALARA Network (EAN) [11].
- Regional European and Central Asian ALARA Network (RECAN) [12].
- Asia Region ALARA Network (ARAN) [13].
- European Study on Occupational Radiation Exposure (ESOREX) [14].

The three regional ALARA networks deal with the optimisation of radiological protection and facilitate the dissemination of good ALARA practices within all fields of activities using ionising radiation (nuclear, industry, research and medical sectors). Their activities are focused on occupational exposure in industry, research, medical and Naturally Occurring Radioactive Materials (NORM) areas, particularly on enhancing and developing competence in radiological protection, with special emphasis on the implementation of the ALARA principle in all areas, both in routine operations and emergency situations. The objectives of the ESOREX are to provide the European Commission and the national competent radiological protection authorities with reliable information on how personal radiation monitoring, reporting and recording of dosimetric results is structured in European countries; and to collect reliable and directly comparable data on individual and collective radiation exposure in all occupational sectors where classified workers are employed.

### *The Western European Nuclear Regulators' Association (WENRA)* [15]

This group 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. The main objectives of WENRA are to develop a common approach to nuclear safety, to provide an independent capability to examine nuclear safety in applicant countries and to be a network of chief nuclear safety regulators in Europe exchanging experience and discussing significant safety issues.

### *US ALARA Committees: BWR and PWR* [16]

The US utilities organised industry ALARA committees in the 1980s to facilitate ALARA good practices and lessons learnt from the spring and fall outages. The General Electric Owner's Group ALARA Committee is composed of ALARA co-ordinators from the 39 US BWR reactors. They meet three times per year.

The PWR RP/ALARA Association is composed of the 69 US PWR reactors including Westinghouse, Combustion Engineering and B&W reactors. European PWRs also are members including Sizewell B, Ringhals and EDF. The ALARA co-ordinators meet two times per year to discuss good and poor ALARA performances in recent refuelling outages and during normal operations.

## *Dose trend analysis*

When designing a new NPP, or when developing or assessing a license application, expectations regarding occupational exposures will certainly be important factors to take into consideration. These expectations can be based on many different types of assessment, including the study of relevant dose trends in currently operating plants. While trends in currently operating plants will not directly reflect what might be expected to occur in new plants, such assessments can provide relative benchmarks with which more detailed estimates, that reflect the specificities of the new plant design, can be framed. In general, and particularly from a regulatory perspective, it would be expected that new plants would perform as well or better than currently operating plants, and exceptions to this in license applications would require clear explanation and justification.

Different types of dose trend assessment can be performed, but typical assessments would include individual worker annual dose averages and trends, site annual collective dose averages and trends, and perhaps average collective dose trends for particular, high-dose jobs.

## *Individual dose trends in NPPs*

In general, the data from the official dose monitoring of European countries suggests that average annual exposures of about 1 mSv for plant utility personnel, and 1.5 mSv for outside/contract workers can be regarded as a realistic goal in the near future for existing power generating NPP (Figures 1a and 1b), [17].

For new NPP this could mean that – after a start-up phase – the values of a rolling 3-year average may realistically remain below 1 mSv for plant personnel of a new plant and 1.5 mSv for outside/contract workers.

Figure 1a. **Dose trend for own personnel in power generating NPPs in Europe: Mean annual dose from 10 European countries**

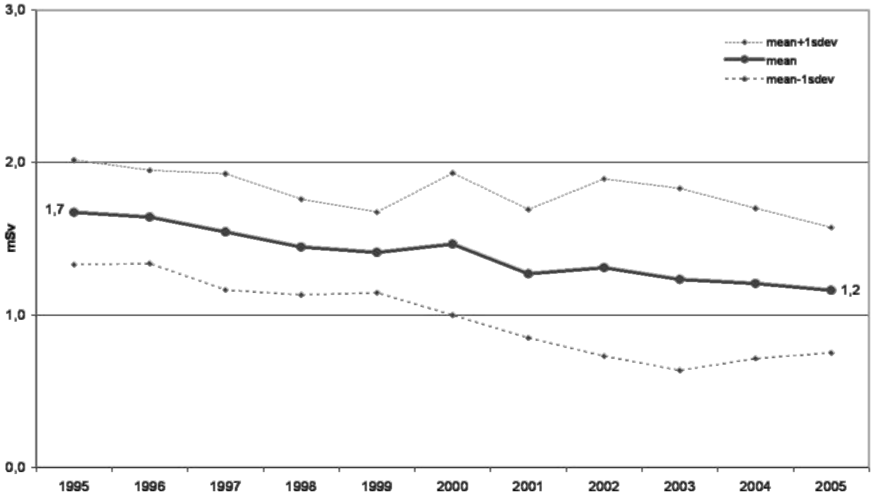
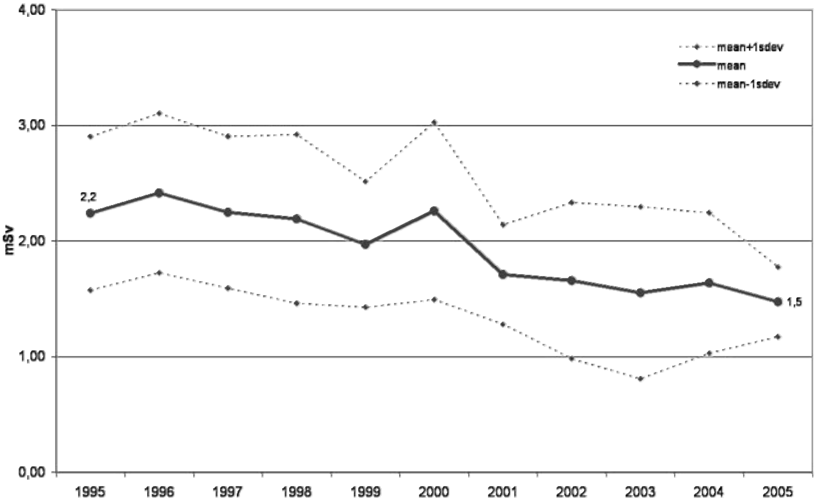


Figure 1b. **Dose trend for outside workers in Europe: Mean annual dose from 10 European countries**



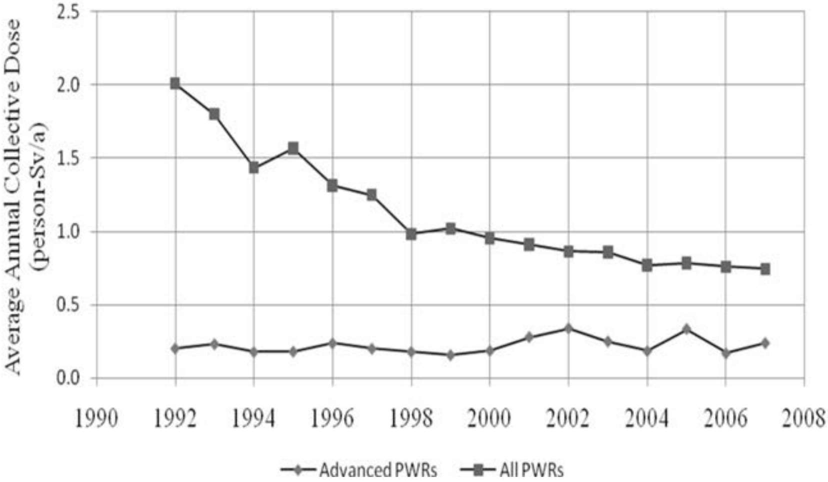
Source of the two figures: Oxford University Press (http://rpd.oxfordjournals.org).

### *Site collective dose trends in NPPs (from the ISOE database)*

Since about 1990 the average annual collective dose at NPPs has fallen by more than a factor of 2. For PWRs, this evolution is from just over 2 person-Sv/a per unit to under 0.75 person-Sv/a per unit. For BWRs, the decrease is slightly less, from about 2.6 person-Sv/a to 1.5 person-Sv/a per unit. For the new generation PWRs the current annual collective dose is closer to 0.25 person-Sv/a per unit.

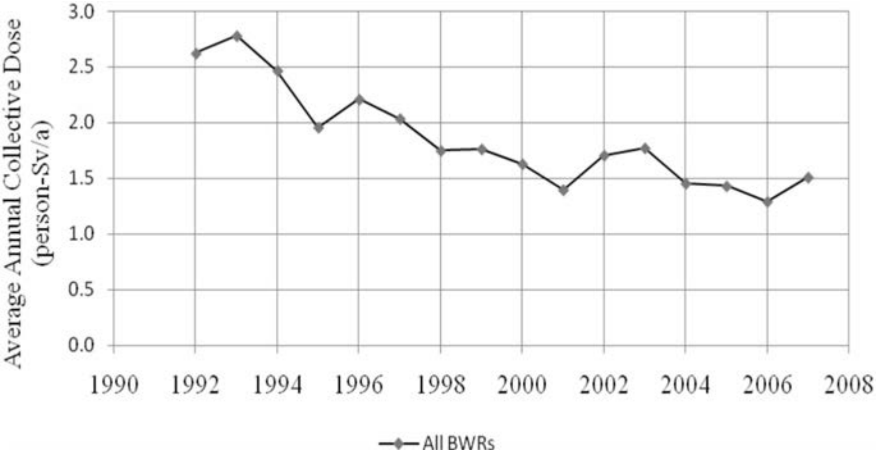
These collective dose trends are shown in Figures 2 and 3 below [9]. The data is taken from the ISOE Programme, and the advanced PWRs represent the latest French and German designs, whereas the PWR and BWR single-unit averages represent all PWR and BWR plants in the world. It should be noted that study and data of trends in advanced BWR plants (ABWRs), currently in operation in Japan, are not available but would be useful in assessing how much better modern BWRs may perform than the current BWR fleet.

Figure 2. **Average annual collective dose trends for all PWRs and advanced PWRs**



Source: Figure based on data from the ISOE Programme.

Figure 3. **Average annual collective dose trends for BWRs**



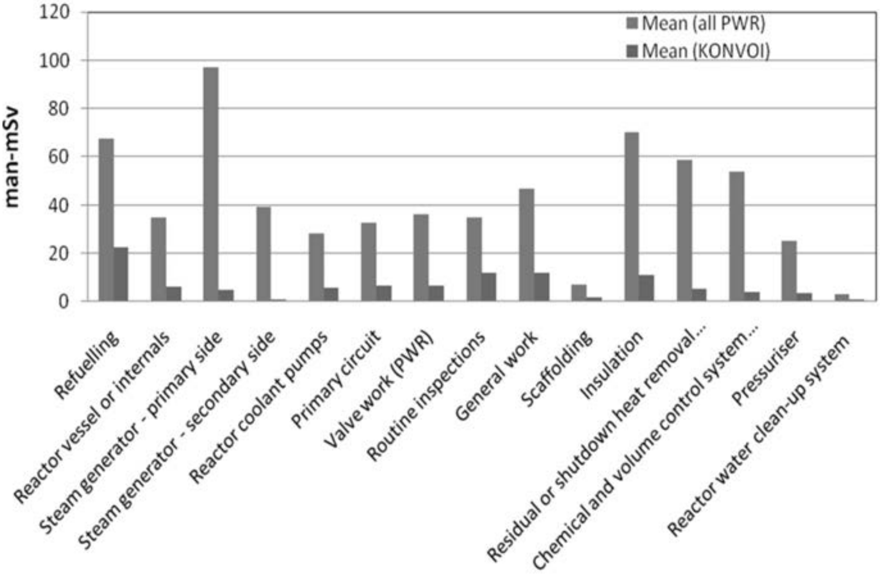
Source: Figure based on data from the ISOE Programme.

Given these trends, it seems reasonable that utilities wishing to build new NPPs, and regulatory authorities involved in the assessment of license applications for new nuclear plants would take this experience into account in establishing exposure benchmarks for planning. According to the current trends, annual collective dose benchmarks for new units, could be in the order of 0.25 person-Sv/year per unit for PWRs, (see also Section 3.5 of this report). Benchmarks for BWRs should be somewhere below 1.5 person-Sv/year per unit, but again, further data is needed in order to make a more accurate assessment for BWRs. Based on current good practice and experience, such criteria could be useful in identifying the most appropriate protection options.

### *Jobs specific collective doses analysis*

Trend analyses of the average annual collective dose per job were performed for 15 different jobs in eleven German PWRs for the years 1992-2006. The plant-specific collective doses show a broad variation, not only between the different generations of PWR but also between the different jobs and within each job over the years. Decreasing dose trends are not always obvious, except for jobs like "reactor vessel or internals" or "valve work" (See Figure 4). Relevant for the present characteristics of job-specific collective doses in German PWRs are the three youngest KONVOI-plants (year of commissioning: 1988). The job-specific average annual collective doses in these plants are considerably lower compared to all other German PWRs. During the years 2001-2006, the average annual collective dose in these KONVOI-plants amounts to only about 15% of the total average. Within each job the collective doses vary considerably over the time. This variation results partly from plant-specific work requirements but also from sparse data. Therefore these statistics and time series can only give an indication of possible job-specific dose levels.

Figure 4. **Average annual collective doses per job in all 11 German PWRs and in the 3 youngest KONVOI-PWR (averaged over 2001-2006)** [6]



Source: ISOE Occupational Exposure database (www.isoe-network.net).

## 2.2 Knowledge management

Knowledge management is the process of systematically and actively managing and improving the stores of knowledge in an organisation. It is a multi-disciplined approach dedicated to the process of transforming information and intellectual/technical assets into enduring value.

In the case of radiological protection for future NPP, this may encompass a very broad range of objectives, including:

- Ensuring adequate traceability among generations of workers.
- Ensuring adequate traceability for decisions made at the design stage and subsequent engineering-change (modification) stages – the recording of the technical as well as management/regulatory aspects of these choices.
- Identifying internal or external best practices and allowing their adoption.
- Organising the collection and the recording of knowledge, including expertise and competences developed in everyday work.
- Anticipating the required tuning to significant changing information technologies during almost one century (as information on technical features is essential during the dismantling phase).

Considering the extended lifetime of future NPPs, as long as 80 years, *i.e.* two or more generations of workers, the way that information about radiological protection decisions will be recorded and made available over the lifetime of the plant is a key issue for the global knowledge-management process. While it could be considered as only an operational issue, it is in fact important to start planning at the very beginning of the plant design, as some specific design features might be necessary to support the knowledge management process during the future plant operation.

Knowledge management is primarily the management of people and of processes, and addresses the commitment as well as the know-how of the workforce. The involvement of the workers, both at the very beginning and in a sustainable way, is fundamental to maintain and furthermore develop a useful database of skills in radiological protection. This database may be considered as one basis, among others, for staff education and training.

The knowledge management methodology framework consists of at least three stages. First a strategy is developed and planned before the beginning of the project. Second, knowledge management is executed during the design and operating lifetime of the NPP, perhaps with improvement during this period. Third, knowledge management during the decommissioning of the plant should be built upon management processes and procedures operated during the previous stages, and should run until the plant is fully decommissioned. Commitment to the active management of knowledge should be a policy decision by plant management, and should include the general involvement of workers.

## 2.3 Radiological protection education and training

### *Several possible levels and types of education in ORP*

Education and training in ORP is a key issue from the design to the decommissioning stage of facilities. Education should be adapted to the worker's skills and field of activities. Since there is a non-negligible risk that there may be a lack of qualified personnel in the near future, it is very important to keep track of experience in order to assure its availability for future generations. The question of education and training of future staff in ORP (maintenance workers, radiological protection professionals from operators or regulatory body) should thus be addressed during the design phase in order to ensure the availability of trained staff throughout the plant's lifetime.

#### *For design teams*

In this case, the objective of the radiological protection training is that designers be conscious that their design may have an impact (sometimes significant) on occupational exposures. This type of training course should incorporate as much as possible examples from the lessons learnt from previous plant operations. Designers should be able to perform, if necessary with the help of radiological protection specialist, some ALARA analyses for the design of components for which they are responsible, and to document these analyses. It is also important to note that training in radiation risk management should be part of training in the other types of occupational risks, in order to have designers optimising the protection against the whole pool of occupational risks.

#### *For ORP professionals*

Education and training methods as well as certification and recognition systems for radiological protection professionals vary widely between countries. Despite information exchange opportunities offered by international organisations (*e.g.* IRPA, IAEA and others, see education platform below) the national education and training as well as the certification schemes are still developed quite independently.

#### *For all exposed workers*

Here also, according to an utility's philosophy, radiological protection education and training of exposed workers may vary significantly, depending on the role of the Health Physicist staff. It is however essential that all workers receive a basic education and training in radiological protection providing the necessary knowledge to be able to protect themselves and their colleagues.

### *Platforms for education and training programmes*

#### *International Radiological protection Association (IRPA)* [18]

The International Radiological protection Association supports initiatives towards harmonisation and standardisation in this field by organising refresher courses at IRPA conferences, by co-operation with international and regional governmental organisations dealing with education and training in RP, and by organising discussion forums at IRPA conferences.

### *International Atomic Energy Agency (IAEA)* [19]

The International Atomic Energy Agency provides sophisticated education and training programmes that follow resolutions of its general conferences. These courses reflect the latest IAEA standards and guidance. These programmes should help radiological protection regulations of IAEA Member States receiving technical assistance to comply appropriately with the provisions in the IAEA Safety Fundamentals and Basic Safety Standards. The strategic plan on Education and Training in Radiation and Waste Safety was endorsed by the General Conference of the IAEA in 2001. A steering committee with representatives from international organisations or associations (such as EC, IRPA etc.) provides advice and support.

### *European Platform on Training and Education in Radiological protection (EUTERP)* [20]

The provisions in the European directives are binding for the EU Member States and have to be implemented into the relevant national regulations with some flexibility to account for national particularities. EUTERP focuses on education, training and recognition activities in the European Union, and establishes close links among relevant projects and organisations. The results of the various projects can be disseminated by the Platform in an effective way throughout the European Union, and can also be used as input for further work.

### *European Network on Education and Training in Radiological protection (ENETRAP)* [21]

The ENETRAP objective is to maintain a high level of competencies in the application of ionising radiation and to ensure the protection of workers, the public and the environment. Its main aim is to better integrate existing education and training activities in the radiological protection infrastructure of European countries in order to combat the decline in both student numbers and teaching institutions, to develop more harmonised approaches for education and training in radiological protection in Europe and their implementation, to better integrate the national resources and capacities for education and training, and to provide the necessary competence and expertise for the continued safe use of radiation in industry and medicine.

### *Co-ordination Action on Education and Training in Radiological protection and Radioactive Waste Management (CETRAD)* [22]

The CETRAD develops proposals for structuring and delivering both education and training in the management of the geological disposal of high-level and long-lived radioactive wastes and spent fuel in geological formations.

### *Examples from the United States*

The National Council on Radiological protection and Measurement (NCRP) as governmental organisation has – as its main mission – to formulate and widely disseminate information, guidance and recommendations on radiological protection and measurement issues and experience. Extensive training and education programmes in several areas are also provided by the US Department of Energy (DOE), for example on ALARA [23], and through the Institute for Nuclear Power Operations (INPO).

In the United States, Radiological protection Manager's (RPM) minimum qualifications are described in an American National Standards Institute document, ANSI 18.1 [24]. This standard states that RPMs should have a college or university degree in health physics or related sciences/engineering. In addition, they need to have five years of experience at operating nuclear plants, including supervisory experience during a refuelling outage.

The US nuclear industry embarked on a national training and accreditation training programme after the April, 1979, TMI-2 Nuclear Accident. The job qualification and training requirements for each employee and contractor in the ORP department are listed on a qualification matrix prepared and updated by ORP supervision. Regulatory inspectors review the ORP qualification matrix to assure qualified personnel are performing work activities in the area of radiation safety.

Some nuclear plants are using practical ORP skill challenge exercises for all radiation workers, including employees and contractors. These challenge exercises assure that practical ORP skills *e.g.* dress-out, contamination control techniques and ORP requirements are retained by radiation workers.

# 3. Integrating occupational radiological protection criteria during the design process

## Key messages

ORP design objectives should be based on a "gap analysis" prepared by both the utility and design groups, analysing good practice in current plants and what is proposed for the new facility. Results of this "gap analysis" should be considered in integrating ORP principles into the design process in order that planned protection is optimised and estimated occupational and public doses are ALARA. So called "ALARA check-lists" should include consideration of aspects such as general system/components, system layout, component configuration, accessibility, radioactive waste handling, shielding, and others. Further, design decisions on ORP should be achieved in consultations between the utility, design-engineering and/or regulatory body personnel, and should also include considerations of risk transfer issues arising from design considerations. Among important factors to be considered are the operating life for future plants of around 80 years, which will cover two or more generations of workers, clean-up activities and progressive demolition of the plant. In addition, the advanced remote monitoring technologies and, wherever possible, robotic equipment have become significant tools in reducing future occupational doses. Use and compatibility of these technologies should be considered at the design phase. Specific attention should be paid to the development of new technologies and their compatibility with existing systems.

## 3.1 Organisation to integrate occupational radiological protection criteria in the design process

### *Determination of ORP objectives*

Early in the design process, utility and architect-engineering personnel should discuss the overall vision for the facility as regards exposure management. In addition to documented regulatory requirements utility management may have other objectives that should be stated to the architect-engineering or in-utility design personnel. An example may be the minimisation of routine access requirements to plant areas exceeding a pre-selected radiation-field threshold. Another example may be an objective to reduce the average annual collective dose to workers (or individual dose to a worker) at the plant to less than a pre-selected number (*e.g.* a percentage of the accrued dose at currently operating plants of that utility or in that country – see Section 2.1). In those discussions, the utility management may also wish to clearly describe to the design engineering personnel, design-related exposure-management issues faced in current plants that they wish resolved in the design for the new facility.

Such a discussion should then be encouraged to include the architect-engineering or other design engineering personnel describing items for resolution that they have observed from design issues at current plants and from the review of facility design considerations, even as relates to promising/proven design input from facilities other than NPPs. At this stage, care must be taken to consider exposure management in the context of the type of plant being designed. The exposure-control issues related to BWRs, CANDU reactors, high-temperature gas reactors, and PWRs (to name some but not necessarily all relevant reactor types) are substantially different. When considering design elements regarding radiation safety, personnel with training and experience for the reactor type of interest should be used in the design input and review process.

With both the utility and design groups bringing a perspective to what may be called a "gap analysis" between what exists in current plants and what is envisioned at the new facility, a focused discussion can be held to lead to consensus understanding of the objectives for the design. That is, the design objectives that are to be met should be specified in as much detail as feasible as early in the process as possible. There is recognition that if a plant of a standardised design is being planned for construction, there may not be as large a number of design changes that may be reasonably possible to implement at the new facility as for a uniquely designed facility. On the other hand, standardisation has the potential to avoid having unanticipated design issues that adversely affect radiation dose impact of the facility.

### *Screening process*

Design considerations for incorporating sound radiation safety principles into the design process have as an objective achieving occupational doses and doses to members of the public that are ALARA or optimised. The design process for a NPP is a structured process, to ensure that all identified relevant design input is taken into account. For that purpose, the applicant for a construction or operating license for a NPP (and/or their architect-engineering partner) may use, early in the design process, a screening design considerations check-list or similar means to identify factors that are considered to be applicable during the more detailed phases of the design process. Examples of factors related to radiation safety that might be found on such a check-list are:

- Area radiation monitoring capabilities.
- Optimisation of dose to workers and the public.
- Associated radiation assessment of means to ensure that optimisation and minimisation of radioactive wastes are performed.

### *Radiological protection and ALARA design review committee*

One of the methods employed in the United States during the construction boom of nuclear units in the 1970s was the implementation of a radiological protection and ALARA Design Review Committee for each plant under design and construction. The committee and its members each have the responsibility to identify omissions, deficiencies and problem areas in dose reduction. Solutions to identified problems should also be provided. The committee functions in an advisory capacity to the project manager and the plant owner. Approaches that have been used are described below:

- Purpose
  To conduct ongoing independent design reviews of the nuclear unit including facilities, systems and equipment.
- Objective
  To verify that the NPP design assures that occupational exposures will be ALARA and in compliance with applicable ORP criteria, regulations and engineering standards.
- Scope
  Committee to review the design and operational objective of the protective features required for sources of radiation within the plant. All systems and aspects of the design which can result in occupational radiation exposure shall be considered, including maintenance, in-service inspection, refuelling and non-routine operations.
- Evaluation
  Includes a review of the radiation aspects of the facility layout, predicted dose rates, radiation access control, shielding, ventilation, radiation monitoring, contamination control, radioactive waste handling, health physics facilities and equipment.
- Decision making and documentation
  Decision making criteria should be made explicit. The various factors to be taken into account in the optimisation process have to be listed (cost, safety, feasibility, impact on operation, impact on dismantling etc.). The final decision to implement specific design options or not should be documented and archived.
- Membership
  A standing committee should be appointed for each nuclear unit during its inception representing at least the ORP, operations, engineering, and maintenance groups. The chairperson should have extensive and broad experience in the area of radiation engineering and health physics.
- Meeting frequency
  Formal ALARA design review meetings should be held at least once during each major design phase including conceptual, preliminary design, final design, construction etc. The committee should be convened as appropriate.
- Basis for review.
  The basis for the review shall be based on requirements contained in the following reference sources:
  - General design criteria from regulator.
  - Regulatory guides.
  - Industrial code requirements (ANSI, ASME, etc.).

  - Owner recommendations.
  - Scientific bodies.
  - Alpha values as a tool for decision making.

- Examples of documents to be reviewed:
  - Environmental report, safety analysis report.
  - A/E design criteria.
  - System descriptions.
  - Drawings.
  - Calculation books.
  - Reports.

- Examples of subjects to be reviewed:
  - Site layout and arrangements – radiation site boundaries and areas, ingress and egress routes and controls, parking facilities, e.g. dose rates at boundaries.
  - Shielding and exposure levels – criteria, source identification, calculations and design factors. Normal operations, anticipated operational occurrences, and credible accident scenarios should all be considered.
  - Airborne radioactivity control system – flow pattern (hot to cold), pressure differential, air change rates in cubicles and buildings i.e. containment purge, local ventilation, and recirculation and exhaust filter requirements.
  - Contamination control systems – surface texture and finish, control of leaks and spills (basins, curbs, drainage, overflow pipes and vents), hose connections and water supply, ease of filter replacement, equipment decontamination facilities, storage for contaminated tools and equipment and personnel decontamination facilities.
  - Sampling and radioactive analysis facilities – including sampling stations, laboratories, counting rooms and radioactive waste facilities.
  - Radiation monitoring systems – areas monitors (number, location and range), process monitors (on-line or off-line, location, background, sensitivity, range, readouts, annunciators, alarms, control system, recorders), emergency monitors (fuel handling area, containment, control room habitability).
  - Radiation access control and health physics facilities – including gatehouse, dosimetry, badge racks, radiological protection control points (singular access to radiation controlled area is desirable), first aid facility for potentially contaminated injuries, facilities for distribution, cleaning, monitoring and storing of protective clothing and respiratory protective equipment.

### *Utility, design-engineering specialist and regulatory body communication*

A portion of any discussion of radiation safety between the utility, design-engineering, and/or regulatory body personnel should be the consideration of risk transfer issues that might arise in the design process. An example may be the potential balance between the control of potential plant effluent to reduce dose to members of the public and the control of dose to the workers. If additional radioactive material is maintained inside the facility rather than becoming a portion of the plant effluent, the dose to the workers may increase. Regulatory requirements, especially regarding cost-benefit analyses for introducing additional design elements to reduce dose to workers or the public, will be expected to be one key element in such a discussion.

## 3.2 Occupational radiological protection criteria at the design stage

### *Plant life management design considerations*

Many existing plants are applying or will apply for lifetime extention. Plant life management plays an important role in the determination of cost/benefit analysis with respect to ALARA design features. Factors to be considered include:

- Recognising the importance of the design basis for plant life-cycle planning, in particular with current global thinking regarding plant life expectancies, it is important for future plant designers to carefully consider the design implications of as long as 80 years of plant operation, such as the need to upgrade or replace major components.
- The need to provide removable shielding and structural walls for plant cubicles for the ease of large component removal and replacement every 20-30 years.
- Monitoring of buried plant carbon steel pipes which are candidates for replacement every 20-30 years to preclude leakage into the environment.

### *Future NPP "end-of-life"*

Feedback from the available experience in decommissioning should be integrated at a very early stage of the design of the future NPPs.

Information from NPPs currently in decommissioning is essential for this planning. Both technical and regulatory issues need to be considered in order to avoid designs and operating procedures which could increase the nature and the number of difficulties encountered during decommissioning and dismantling.

First nuclear plants were designed for an operating life of about 30 years or less. Newer plants are designed for as long as 80 years of operating life. As such, it will be important to consider the aspects of ORP addressing future clean-up activities and progressive demolition of the plant. Thus, there is a need to consider this objective during the design and commissioning phases in order to provide assurance that the appropriate elements of radiation safety will be included to protect workers, the general public, and the environment during future decommissioning activities. This will assure agencies responsible for review or audit of the decommissioning project that the requirements for ORP have been satisfactorily addressed.

As an example, reference IAEA Safety Reports Series No. 36 [25], provides useful information on this subject.

### *Use of proven technologies*

To the extent feasible, the facility design should use proven, industrial scale dose-savings features. Some examples are the use of permanent shielding rather than temporary shielding where feasible, the use of permanent work platforms when feasible to reduce the need for construction of temporary scaffolding, and the use when feasible of "quick" electrical disconnects rather than more time intensive electrical de-termination and re-termination processes. Further examples may be found by a review of the questions found in Appendix 1.

Generally, the design of an NPP should not use unproven or uncertain technologies in the optimisation process. The use of such new technologies is not prohibited, but if used should be accompanied by adequate evaluation to reduce the potential for redesign and rework processes that may be both time- and dose-intensive.

### *Role of ALARA design check-lists*

In the design process, there are many aspects of the design that can affect dose to workers. The applicant (and architect-engineering partner where appropriate) and the regulator are to ensure that a structured evaluation occurs during the design process, to address questions of import regarding the dose impact of a specific facility design. The check-list of factors potentially having an impact on worker exposures to be considered at the design stage is an essential tool for the screening process. The intent of the listing of these criteria is to bring awareness to the design engineers of those designs to be developed that should consider exposures, and protection optimisation, in more detail.

Either in the screening process or in the ALARA and protection optimisation processes, design engineers should be in communication with radiation safety personnel, to ensure that the perspective of personnel with more comprehensive training and experience in radiation safety is considered in the process. If an architect-engineer is developing the design for an utility, there should be means to ensure that the utility engineering and radiation-safety personnel are aware of and are in consensus agreement with the plans of the architect-engineer.

The regulatory body may also have a separate (but presumably similar) design check-list pertaining to the radiation safety related aspects of the facility design. During the focused meetings on radiation safety recommended above, the elements of the separate check-lists may be discussed. The discussion arising from multiple check-lists from the relevant parties may enhance the design of the facility as regards radiation safety, especially if those discussions occur early enough in the process to affect the design of the facility early enough to remain cost-effective.

Following appendices provide examples of check-lists that can be used by designers:

- Appendix 1 "ALARA design check-list" is an example of a check-list that has been used by one utility for evaluation of proposed modifications for purposes of protection optimisation. For that utility, the programme also includes a process for an early estimation of dose to install the modification, the results of which can be fed back into the design process. While related to modifications, that check-list is included here to describe the elements of design output that might directly impact radiation exposures in a facility. The elements can be outlined to include the following:

  - General structures, systems and components (SSC) design.
  - System layout, component configuration, accessibility, and access control.
  - Management and minimisation of radioactive wastes.
  - Permanent and temporary shielding.
  - Surfaces which may become contaminated and measures to facilitate decontamination.
  - Choices of equipment and techniques for systems containing radioactive materials.
  - Valves containing radioactive fluids.
  - Piping containing radioactive fluids.
  - Tanks containing radioactive fluids.
  - Pumps containing radioactive fluids.
  - Filter or filter systems in systems containing radioactive materials.
  - Heating, ventilation, and air conditioning systems.
  - Process instrumentation controls and sampling.
  - Radiation detection instrumentation or monitoring.
  - New facility design or significant change to an existing facility.

- Appendix 2 "ALARA Engineering design principles" provides the main principles to be applied in the design process to integrate RP considerations

- Appendix 3 "Application of ALARA to facility system design" gives advice for the design of the main systems

- Appendix 4 "Application for construction and/or operating licenses for nuclear power plants – design aspects related to ORP" is intended to provide a higher level outline related to the content that might be expected to be addressed in the application, as focused primarily on input related to judgements of design optimisation for management of estimated doses to workers and members of the general public. This appendix includes the evaluation of the facility's effluent management systems among the items to be considered from an ALARA perspective. While the focus of effluent systems is often on management of doses to members of the public, there may well also be aspects of technology application or avoidance that affect management of doses to the worker. An example may be the shielding of a room used for storage of reactor water clean-up resin in preparation for shipping the resin as radioactive waste. The remainder of this appendix describes elements of the radiation safety facilities that would be expected to be considered in more detail as the design process continues.

### *Example of RP considerations from feed-back experience*

Several topics of great importance for radiation safety, which have been efficiently addressed at many operating facilities, can be classified as good practice and are listed below. They are also expected to be addressed in the next generation of plants.

#### *Fuel design*

Design and test of the fuel elements should show high fuel reliability with respect to cladding leaks, and should prevent debris intrusion and production of activated corrosion products that could be released from fuel surfaces.

#### *Structural materials*

Alloys used in the primary system should be selected to have no significant impact on dose rates, in particular through release of elements that can become activated – for example, cobalt reduction policy in the design. High resistance to the operating conditions and selection of the chemistry and other operating parameters should be in favour of long life time and reduced in-service inspection frequency.

#### *Foreign material exclusion zones*

Provision in the design to help in efficient protection from foreign materials around the fuel pools, above the reactor, and near anticipated breaches of the reactor coolant system. This can help in prevention of fuel and other damage during operational conditions.

#### *Cleanup systems for reactor coolant*

Removal of radioactive contaminants from reactor coolant is very important for radiation safety during operation. Ion exchangers and submicron filters are already proven technology. Recently, new technologies have been tested for removal of colloidal particles by different methods. As one example, isotopic diluents and reacting compounds are added to hot liquid sodium. The reactants isotopically exchange or chemically react with the fission products and are precipitated out of solution in a first cold trap. When the supply of reactants is exhausted, the flow is reversed; the first trap then functions to supply the reactants and the precipitation occurs in a second cold trap. Consideration should also be given to improve standard design of cleanup systems, and multiple methods are needed to be considered in order to enable contingency actions in case of malfunctions.

#### *Radioactive waste system design*

Radioactive waste processing needs space for waste segregation, water and radioactive waste tanks of adequate capacity for storage of radioactive waste, and the processing systems related to radioactive waste management requirements. The proper facility and procedure design of radioactive waste processing should assure that doses are ALARA for operation and during service and maintenance activities.

### *Shielding*

Shielding design should be documented to comply with prescribed radiation safety criteria. These criteria can be different for operation and for accident conditions. Radiation source terms should be defined as a basis for shielding calculation. In some cases it might be practicable to consider temporary shielding provisions, in particular for outage and maintenance work on primary system components which cannot be shielded permanently.

Biological shielding for gamma and neutron radiation in the reactor containment should assure acceptable exposure of radiation workers inside the containment during operation if such work might be necessary.

### *Platforms and lay-down areas*

Provisions for platforms required for safe work should be included in the design as well as storage of scaffolding and temporary shielding materials inside containment and similar small improvements important for radiation safety specific locations or for contamination control. Enough space for lay-down areas is necessary for maintenance activities to assure easy access and to reduce time spent in the radiation area.

### *Modular design*

Modular design of primary components reduces installation time and facilitates contamination control. Such examples are integrated reactor vessel head together with ventilation; easy replacement of radioactive valves; and modular design of reflective insulation on the pipelines for easy installation taking into account in-service inspection locations.

### *Fuel pools and sumps designs*

Fuel pools design and commissioning programmes should assure no leakage and easy decontamination of the pools and fuel transfer canals, particularly if this is required for inspection or maintenance of fuel transfer equipment. Decontamination systems for reactor pools and the sumps should be foreseen. Design of filtering and cleaning systems should take into account the need to achieve doses that are ALARA during operation, maintenance and radioactive waste transport.

Leak detection systems related to fuel pools should be of proven design to be operable and maintainable during the life time of the plant.

### *Radiation monitoring system and remote technology*

Installed area dose rate monitors and air contamination monitors should be sensitive enough for normal conditions and also of high range to give reliable information in case of accident conditions. The monitoring channels should be calibrated easily without a need for use of high radiation sources. The locations for permanent monitors should be carefully selected.

Remote monitoring technology should be considered during facility design to be easily installed at locations where such monitoring may be periodically necessary for operation and maintenance activities (see Section 3.3).

### *Access to and exit from controlled areas*

Provisions for ORP exit control points and facilities, such as contamination monitors, laundry, lockers for normal operation, during outages and major maintenance should be considered in the design to assure efficient access and exit control logistics, and at the same time proper contamination and dose control of workers.

Access to the RCA is provided with the registration of and control features for the workers' individual exposures. Access to contaminated areas should be provided with clothing change facilities and locker rooms. Contamination control measures for workers should be provided at the exits from highly contaminated sub-areas/rooms/buildings and should consider the need to detect hot (highly radioactive) particles. These measures should include local control points and local radiation monitors.

Sufficient space for local and exit control points should be provided in the design of the nuclear facility. Exits from RCA should be provided with whole body contamination monitors. These facilities might be combined with first walk-through monitor with a higher alarm level. Dosimetric check-out of the workers should be provided at the exits from RCA. Showers and facilities for personal decontamination should be part of the exit facilities, or should be located near-by in the supervised areas. The design should be capable of handling the appropriate number of people required for maintenance and the other outage related activities.

The rooms and laboratories related to radiological protection work should be practically located and sized to include all relevant radiological protection duties, for example: instrumentation shop and calibration, RP and radiochemistry radioactive source storage, radiography source storage, contamination control laboratory, respiratory protection equipment storage and distribution, gamma spectrometry and radiochemistry laboratories, post-accident radiation monitoring and sampling, control centre for video monitoring of high-radiation work progress in RCA and for teledosimetry.

Whole body monitoring after exit from a RCA, and related dosimetric services should also be provided with appropriate rooms and laboratories.

### *Classification and delineation of areas*

The design of new reactors should include the identification of different radiation zones within the plant. According to the EURATOM BSS [4], the competent authorities shall establish guidance on the classification of controlled and supervised areas relevant to the NPP circumstances. A supervised area is defined as an area subject to appropriate supervision for the purpose of protection against ionising radiation. A controlled area is an area subject to special rules for the purpose of protection against ionising radiation or of preventing the spread of radioactive contamination and to which access is controlled.

In general, access to the areas with dose rates estimated to be > 1 mSv/h should be provided with equipment, barricades and monitoring devices in the design phase. The access to the areas with dose rate > 10 mSv/h should be equipped with appropriate alarm and monitoring equipment which can be operable in case of a need and activated for personnel safety.

New plant designs should, as far as possible, eliminate high radiation (external, internal, airborne) areas. For those high radiation areas that are not possible to design out, specific design features will be needed to assure personal safety. The design should prevent access to areas (or existence of hot spots) where very high doses can be received in one or two days. For example, areas with dose rates over 100 mSv/h would require that safety measures are incorporated in the design to prevent uncontrolled access to such areas. Guidance for design of new NPPs should suggest that no exposure areas at or above 100 mSv/h during operation (or standard refuelling outages and inspection work) would be foreseen, based on design parameters and estimated radiation source terms. The design of new NPPs should favour more passive radiation safety design features.

### *Dose rate zoning*

NPP buildings and controlled areas should be assigned according to the different exposure zones. It is expected that the identification of controlled areas will be provided in design and licensing documents to facilitate the assessment of possible occupational exposures.

Safety assessments should cover two distinct cases: normal operation and accident scenarios. Equipment and rooms or areas needing operator attention or action during either case should be identified as best possible, and basic information such as dose rate and time required for work should be provided (through time/motion studies for example). A risk informed design approach can be combined with deterministic scenarios, particularly for the assessment of exposures in accident situations.

A common approach is to estimate operational dose rates for use during design basis accidents based on annual dose limits. Typical levels can be, for example, 10 mSv, 20 mSv or 50 mSv in 2 000 hours (in a working year). Other values might also be selected depending on their intended use, for example designing for exposures to be ≤ 6 mSv in a year might address the definition of radiological controlled areas. Using design criteria of ≤ 1 mSv in a year might be used for development of radiological supervised areas. Note that 6 mSv corresponds to categorisation of exposed workers as proposed by EURATOM BSS (category B) [4]. These levels should be related to normal operation.

In addition to using dosimetric criteria to define controlled and supervised areas, other sectors of the plant may be defined at the design stage based on assessed dose rates. For example, some areas may need to be defined as high radiation, or locked high radiation areas. Definition of these areas will depend on national regulations, but values such as dose rates > 1 mSv/h or > 10 mSv/h have been used for such definitions.

## 3.3 Use of emerging technologies

The use of remote monitoring technologies is becoming common in NPPs. To date, this has usually meant using audio/video camera and teledosimetric systems to visually and radiologically monitor worker activities in elevated radiation fields, or to visually monitor equipment so that worker entry into an elevated radiation field would not be required. At some plants, another use is monitoring of controlled areas entry and egress that may not be staffed full-time by radiation-safety technicians. When designing a facility, engineers should consider a broad use of remote technologies, in consultation with ORP and plant operation experts, within the proposed facility. Therefore, the incorporation of hard-wired or wireless data transmission equipment into the plant design should be considered, as should establishment of an area in which personnel oversee the output of the various remote monitoring devices. There is a need to note that use of remote monitoring technologies may apply to multiple plant objectives; in this case, not only may dose be reduced but also craft workers and their supervision may use the information to enhance work-crew efficiency and effectiveness, both on the current work activity and in future work activities via enhanced training using lessons learnt from viewing the audio/video "tape".

The use of robotic equipment for the performance of inspections, and other selected work activities is also a technology which continues to emerge in the NPP environment. The design engineer may wish to consider the use of robotics as staircase and floor designs are developed, so that robotic equipment may be more easily employed for use in elevated radiation fields, in lieu of the need for entry by humans. Similarly, designing for use of automatic or remote inspection and welding technologies in areas such as BWR drywell nozzles and PWR steam generators should be considered, to reduce the numbers of work hours and dose for outage (and selected on-line) activities.

Specific attention should also be paid by the designer to the development of new technologies which are not yet implemented in existing NPPs, but may improve ORP in the future [7].

## 3.4 Use of design standardisation: examples of existing approaches

### *France*

France's nuclear programme is a good example of the advantages of fleet-wide standardisation. France standardised early on with two Westinghouse PWR designs: 900 MWe, 1 000 MWe and most recently with 1 300 MWe PWRs. The economies of cycle have benefited Electricité de France (EDF) from the procurement of plant equipment in the construction phase and centralised planning and training during the operational phase. Having common spare parts for standardised nuclear fleet greatly simplifies the inventory of parts which must be maintained for emergent plant maintenance needs. This approach also greatly facilitates the training of qualified nuclear workers, who need far less "site-specific" training and experience to quickly and efficiently perform maintenance tasks.

### *ISO and IEC*

International Organization for Standardization (ISO) and the International Electrotechnical Commission (IEC) play a significant role in developing and distributing technical standards for radiological protection devices and measurement techniques. While these are not specifically related to ORP, these standards are generally developed by knowledgeable experts using their own operational experience to assure that the standards are relevant and reflect actual good practice.

### *United States*

Standardization of the Nuclear Steam Supply System (NSSS) and Balance of Plant (BOP) design has proven to be an important consideration for new NPPs. The 1st generation of nuclear plants had three sites in the US which were designed under the duplicate (*e.g.* Byron and Braidwood, Units 1 and 2, Westinghouse PWRs) NSSS and BOP design philosophy.

The Byron and Braidwood duplicate units facilitated the design, construction and operational phase of the plant's life cycle. After over 20 years of successful operation, both sites have consistently scored high performance ratings from the Institute of Nuclear Power Operations (INPO).

In the Byron and Braidwood design phase, cost efficiencies were achieved in the shielding design calculations, the instrumentation and equipment procurement and the training of new operators and support technical staff. Operating experience from the Zion site [26] was carefully examined in the design process of Byron and Braidwood 9 [27], in order to incorporate good practices from the Zion PWR operating experience, from a dose reduction perspective, into the Byron and Braidwood designs.

During operational phases, Byron and Braidwood technical and support personnel continue to have a distinct advantage during staff sharing for refuelling outage: the duplicate units reduce the amount of on-site orientation to train borrowed staff for the support of refuelling outages.

## 3.5 Occupational radiological protection considerations in the design of the EPR

The newest reactor to be constructed is the EPR (known as the European Pressurised Reactor in Europe, and as the Evolutionary Power Reactor elsewhere), units of which are currently being built in Finland and in France. This is an evolutionary, standardised design, and may be constructed in several countries beyond Finland and France. This section provides information on the radiological protection approach that was taken during the EPR design, and has been provided by EDF [28-31].

### *ORP objectives for the EPR*[2]

In order to optimise the protection of workers (both in terms of collective dose and individual dose) during the operating period of the EPR, the following issues are addressed:

- Feedback and best practices at current nuclear power reactors.
- Optimisation of protection for the most exposed workers (thermal insulation installers, welders, mechanics etc.).

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[2] Appendix 5 "Optimisation of occupational radiological protection in the design of the new European pressurised reactor (EPR)".

- the need to intervene, in particular for maintenance work, during operations at power in order to improve the availability of the nuclear reactor fleet, while still complying strictly with ORP standards and regulations.

- The objective of achieving the best (optimal) level of ORP for all workers.

Starting from the best performance of 0.44 manSv a year per reactor unit among the current French NPPs (reference dose), the overall gain in terms of dose is expected to be 21%, achieving the objective of 0.35 manSv per year per unit. This result is achieved by gains in several specific areas, also taking into account exposure increases that are assessed as a result of the structural changes needed to achieve the gains.[3]

**Exposure gains**

| | |
|---|---|
| 13.9% | due to source term or radiation field reduction. |
| 2.9% | due to steam generator improvements. |
| 2.8% | due to primary circuit design. |
| 2.6% | due to thermal insulation improvements. |
| 2.3% | due to fuel management (excluding shutdown). |
| 1.9% | due to site logistics. |

**Exposure losses**

-4.5% due to work in the containment of units operating at power.
-0.6% due to the reactor vessel design.

As a strategic priority for the EDF Group, ORP is becoming less confined to the interest of a small group of people, and is becoming a cross-functional area where multi-disciplinary team work is of paramount importance from the very start of the design phase.

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[3] The sum of the shown percentage shall give the net gain.

# 4. Evaluation and integration of occupational radiological protection cost in the design process

## Key messages

The evaluation of investment costs related to ORP at the design phase is a complex process that requires the estimation of future expenses, and as such involves large uncertainty. To facilitate future cost savings, flexibility should be incorporated in the design so that enhanced control of radiation exposures can be implemented as technologies emerge over the period of operation of the facility. Life-cycle cost-benefit analyses should be performed at the design stage as a function of the utility's vision of dose objectives, for example, for workers to simply meet dose limits, or to do significantly better. Another factor is equipment reliability and the need for replacement of components. Often, the least-cost equipment from the perspective of initial design and construction is not always the least-cost design over the plant lifetime when working hours and dose accrued in maintenance processes are considered. Among factors to be considered is the "alpha value" (cost per unit dose), which can be used to assist in making judgements of whether a planned engineering change or modification is warranted.

## 4.1 Identification of investment cost related to occupational radiological protection

Determination of the cost-benefit ratio regarding the decision to build new NPP is a very complex process involving both factors that are easily quantifiable and those quantifiable only with difficulty and uncertainty. Even in focusing on the cost-benefit ratio related only to radiological protection aspects of design and operation of a proposed facility, accurate estimation involves thorough thought processes and may still involve substantial difficulty and uncertainty. The following are examples of elements that may be considered as design aspects primarily related to control of radiation exposure to workers which could enter in the evaluation of the cost of occupational radiological protection:

- Removal and replacement of some large equipment (*e.g.* pressuriser, steam generators, reactor coolant pumps etc.).
- Easy removal of medium-sized equipment for maintenance in lower radiation level zones.
- Controlling access to the areas of the plant in which radiation safety measures are imposed via physical or other barriers.

- Shielding of structures, systems, and components – including both fixed shielding and provisions for placement of temporary shielding.
- The use of higher-density or other concrete chosen specifically for exposure reduction purposes.
- The use of thicker steel or other doors chosen for exposure reduction purposes.
- Paintings and coatings chosen for the ability to be cleaned (decontaminated).
- Laundry or similar systems for handling of potentially contaminated clothing.
- Provisions for control and decontamination of tools and other equipment that may become contaminated.
- Ventilation and associated filtration systems to control airborne radioactive material.
- Mechanical and chemical filtration systems to control radioactive material and its transport in liquid/fluid systems.
- Systems for continuous or on-demand measurements of ambient exposure rates or airborne concentrations of radioactive material.

There are numerous examples of design decisions that may affect multiple objectives. One such example would be the construction of a permanent work platform from which access to a component within a radiation field would be achieved. The construction of the platform might contribute to enhanced reliability or maintainability of that component, reduced working hours to construct means to access the component, enhanced industrial safety of workers accessing the component, and enhanced radiation safety by reducing the time workers spend accessing the component. The offsetting disadvantage may be a slightly higher cost during the initial construction of the facility. In any case, the effect of the design decision on multiple objectives, including the effect on radiation safety, is to be considered in the cost-benefit analysis.

## 4.2 Some life-cycle cost-benefit questions

The optimisation of a facility design as regards the costs and benefits to ORP is to be performed. It is not the intent of this report to describe all the cost-benefit methodologies which can be used by the utility and the facility designers. Rather, it is the intent of this report to provide some elements to be considered in the decision making process.

One complex element of developing the design of a NPP for operation for as long as 80 years is defining the level of collective and individual dose that is desired across the years of operation and to incorporate flexibility in the design to take advantage of means to enhance the control of radiation exposure as technologies emerge over the period of operation of the facility.

The following are examples of the types of life-cycle cost-benefit questions which may arise during the decision making for what is and is not likely to be an optimal design from a dose-management perspective.

### *Use of a facility dose goal using current, probable, and visionary dose criteria*

The facility design is of course required to meet current dose limits, may fix its own dose constraints, and is likely to be required to demonstrate the use of a process implementing optimisation. The designer will have to take into account a value such as 100 mSv/5 years and depending on the country 20 mSv/year as an individual dose limit. The utility may wish to design to what it considers might be the dose limits at some point in the future, for example, such that projected doses to the most highly exposed individual workers would be maintained in the order of 10 mSv/a or even 5 mSv/a. As has been shown in Chapter 2, overall worker average doses are already in the order of 1 mSv/a. The utility may wish to fix its own dose constraints for operation, either in terms of worker average doses, or unit/site collective dose, again recalling that Chapter 2 has shown that newer PWRs are already operating in the 0.25 person-Sv/year range, and BWRs are operating in the 1.5 person-Sv/year range, with collective doses at both PWRs and BWRs trending lower with time.

In current good practice, all utilities strive to keep all workers below dose limits, and most utilities internally fix dose levels below which they try to keep workers and above which they begin some level of investigation depending on how seriously such values have been exceeded. These internally fixed levels are now referred to as dose constraints. As such, good practice in facility design should take into account both the regulatory requirement to keep worker doses below applicable limits, and the operational objective of keeping worker exposures below internally established dose constraints. Both of these should be assessed, and assured as best possible, over the full lifetime of the plant.

### *Use of decommissioning dose and cost implications in the facility design*

The utility is encouraged to think beyond the proposed operational period for the facility, to reduce dose and costs of decommissioning, as it considers the original plant design. An example may be the construction of structures, systems, and components that are designed to reduce the likelihood of onsite soils and waters becoming contaminated by radiation due to spills or leaks. Design elements that may be conducive to reduced likelihood of such contamination include the use of less buried piping, leakage detection systems, means of monitoring the integrity of piping, and piping specifications for maintained integrity (or ease of proactive, *i.e.* "before-leak", replacement) in the projected environment for the lifetime of the facility.

This factor may be considered important both for controlling occupational radiation exposure but also maintaining control of licensed material onsite and reducing the potential environmental impact of the facility.

### *Equipment reliability and maintainability in a dose management context*

Facility designers should consider optimisation in designing for equipment reliability and maintainability. Dose management is facilitated when higher exposure rate areas are entered as infrequently as possible for equipment maintenance, and when as little time as possible is spent in those higher exposure rate areas to perform maintenance activities. That is the reason why facility design should normally place operating panels outside of higher radiation areas and why quick-disconnect electrical and mechanical connections should be used when reasonably feasible. The least-cost equipment design from the perspective of initial construction may not be the least-cost design over the plant lifetime when working hours and dose accrued in maintenance processes are considered.

Minimisation of time to access areas is another consideration in initial plant design. An example may be the design of the equipment hatch for access to the drywell at a BWR. A traditional design may include a stacked set of concrete blocks to be removed at the start of an outage requiring drywell access. Alternative approaches using steel or concrete on tracks, enabling the shielding to be rolled away from the entrance or using water shields in lieu of concrete shielding may be feasible. The exposure-rate-reduction purposes for the shielding (generally for design base accident management) must of course be satisfied. Consideration of alternative designs may allow for reduced outage duration and reduced accrued dose during an outage.

### *Support facilities*

Adequate space and equipment must be made available to support the ORP programme at the proposed facility. Included among those functions to be supported are administration, work planning, worker briefing, dosimetry, instrumentation, respiratory protection, and remote monitoring. The reason for placement of such a list in this section on economic aspects of plant design is to ensure that the plant designer is aware of choices to be made by the utility. For example, the utility needs to decide if radiation-detection instrumentation calibration and repair should be performed at the facility or at a remote location. This function, and others, is important to facility operation and to ORP specifically, and as such the economic question is which portions of such functions are to be performed within the facility as designed, to best support plant operations and ORP. Elements of the dosimetry and respiratory protection functions may be subject to similar questions.

### *Use of the alpha value, or the value for cost per unit of dose*

Many utilities use an alpha, or cost per unit dose, value in making decisions regarding whether or not an engineering change (modification) is warranted. If dose is the only applicable factor in a decision about a modification, then the process is reasonably simple, excluding for the moment how the utility may do present-value calculations. For example, if a modification would save/avoid 0.01 person-Sv per year over the operational lifetime of the facility (80 years), then a total saving of 0.8 person-Sv is envisioned and a facility modification cost of approximately one million Euros (at 1.3 million euro per person-Sv avoided) would be warranted.

There is a range of alpha values used across utilities and across countries. The value chosen in the example above is near the mid-range of values used in the United States in 2008 ($20 000/person-rem or $2M/person-Sv). Some utilities modify the values used internally, depending on whether a particular facility is (or is envisioned to be) among the better or worse performers in terms of occupational radiation exposure. For example, a multiplier of 1 (hence maintaining a value such as $20 000 per person-rem) would in such case be used for an actual (or projected) best-quartile performer, and a multiplier of 2-4 (hence a value more like $40 000-$80 000 per person-rem or $4M-$8M/person-Sv) would be used for a performer in (or projected to be in) a less-enviable position in terms of exposure control.

# 5. Conclusions

The objective of this case study is to analyse existing ORP experience in currently operating nuclear power plants in order to assess how ORP should best be applied in future NPPs. The purpose of this document is to assist in the assessment of ORP aspects of design and license applications for new nuclear power plants by providing a policy and technical framework that can be used for making judgements. It is primarily, but not exclusively, directed to designers, manufacturers, contractors and authorities responsible for regulating and implementing occupational radiation exposure. It identifies the following major issues that need to be considered and incorporated into design:

- Basic ORP principles – justification, optimisation and dose limitation to be maintained through the expected full life-cycle, in order to address international and national guidance and regulations.
- Optimisation should consider not only potential health risks from ionising radiation, but also other potential risks for the workers' health in order to allocate resources in a well balanced way so that the best worker protection is achieved.
- Organisation of training and knowledge management to assure the availability of highly qualified personnel and adequate design-basis documentation over the full lifetime of the facility, from design to decommissioning.
- Active networking in support of information, experience and data exchange and assessment to maintain sustainable implementation of good practice, and ensure an effective traceability and use of lessons learnt.
- Need for the integration of ORP principles and criteria into all components and future operations in order to save time, money and exposure over the lifetime of the facility.

The implementation of approaches and actions to address these issues should, of course, follow available national and international guidance. These approaches and actions should be identified through analyses of operating experience in existing facilities, which can be used to identify the costs and benefits the action may produce in new facilities.

Multi-disciplinary and multi-organisational co-operation on ORP decisions at the design stage is important. Most ORP decisions will include considerations of risk and risk transfer issues arising from design considerations, and thus can best be taken through consultations between the utility, design-engineering and regulatory body personnel. An important tool for design analyses and assessment is the so called “ALARA check-list”, which addresses all components and processes, including general system/components, system layout, component configuration, accessibility, radioactive waste handling, and shielding.

As a part of such decisions, the evaluation of investment and maintenance costs related to ORP will be important at the design stage. Despite the fact that such evaluation is complex and usually involves large uncertainty, the identification of cost-effective ORP at the design stage will certainly lead to the future saving of costs and exposures. These savings are achieved, in part, by incorporating flexibility of maintenance and component replacements already in the design, such that the enhanced management of radiation exposures can be easily implemented as technologies emerge over the period of operation of the facility. Equipment reliability and the need to stock certain replacement components are among the factors to be considered. The “alpha value” (cost per unit dose) is one tool that can assist in assessing costs, but care should be taken to assure that costs are amortised over the full lifetime of the component or process being considered. These considerations can also be used to assist in making judgements regarding whether a planned engineering change or modification is warranted.

Recognising the importance of building on existing experience, knowledge management structures, processes and procedures must be designed into future plants. Approaches to the management of knowledge should be based on current knowledge management practices in operating plants, as well as on approaches developed in other long-term projects, like space travel or fusion reactors, where the duration of the project demands several generations of workers to be involved. The lifetime of future NPP (80 years) has to be considered in such a way that not only training of workers is ensured but also the collection and analysis of practical experience of workers and design-process output is organised from the very beginning.

The need for well trained, skilled and knowledgeable persons in ORP, both during the design stage and during the life cycle of the plant, is another well recognised component, which is essential to the accomplishment of ORP goals during the future operation of the plant. Knowledge management processes will facilitate the training of workers, but will need to be supplemented by broader education and recruiting programmes to assure a sufficient and ongoing supply of workers.

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# *Appendix 1*

# ALARA design check-list

ALARA design check-list sections as are required for all ALARA related engineering changes.[1]

## For all changes

### *Section 1. General system component design*

- Will this engineering change constitute a change in the Final Safety Analysis Report (FSAR) radiation zone classifications both pre-accident (Chapter 12) and post-accident (Chapter 18)?
- Will this engineering change affect area radiation monitor performance characteristics, set points or plant location? If yes, then contact Plant Health Physics for set point change determination.
- Are radiation-damage-resistant and environmentally qualified materials used, when applicable, to reduce need for frequent replacement?
- Are flow restrictions minimised in radioactive systems?
- Are flanged connections provided, where possible, for quick disconnects and access for hydrolysing?
- Are electrical quick disconnects used in design to minimise maintenance time?
- Are components designed to facilitate draining, flushing, cleaning and deconning by mechanical or chemical means?
- Can flushing, draining or cleaning operations be performed remotely?
- Are vertical versus horizontal type heat exchangers used with contaminated fluids on the tube side?
- Have robots or robotic devices been evaluated to reduce or eliminate worker residence time?

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[1] U.S. Nuclear Regulatory Commission (1996), NUREG-0800, FSAR 12.1 and Reg. Guide 8.8, "Information Relevant to Ensuring That Occupational Radiation Exposures at Nuclear Power Stations Will Be As Low As Reasonably Achievable".

### *Section 2. System layout, component configuration, accessibility, and access control of radiation areas*

- Is all equipment located in the lowest dose rate area where practicable?
- Have recent radiation surveys been reviewed to ensure that equipment is located away from hot spots and local high radiation areas?
- Are components located in radiation areas designed for quick removal and installation (e.g. overhead lift points)?
- Are piping, equipment, insulation and shielding designed for quick removal and replacement?
- Are cable and conduit runs designed and routed through low radiation areas?
- Are permanent platforms, walkways, stairs or ladders provided to permit prompt accessibility for servicing or inspection of components located in higher radiation areas?
- Are recording and control devices easily read or manipulated from and located in accessible areas with low radiation levels?
- Are local indicators (e.g. temperature, pressure) positioned and designed to be read from outside radiation areas using remote viewing devices or remote readouts?
- Have permanent or removable transport devices such as monorails or jib cranes been considered?
- Are components requiring frequent maintenance, calibration or inspection located in low radiation areas?

### *Section 3. Radioactive waste*

- Has consideration been given in the design to minimise mixed (hazardous and radioactive) waste and/or radioactive waste generation during installation, operation and maintenance?
- Has consideration been given to the handling and transport of radioactive waste materials?
- Are radioactive waste capabilities available for solid radioactive waste, flushing and decontamination liquids?
- Has consideration been given in the design to minimise or preclude the generation of gaseous contamination during installation, operation, and maintenance?

### *Section 4. Permanent and temporary shielding and geometry*

- Has the use of permanent shielding been considered to maintain radiation levels at a minimum and prevent the need for repeated installation of temporary shielding?
- Are attachment lugs incorporated into design to allow easy installation of temporary shielding blankets?

- Are proposed shield designs based on plant-specific source term information?
- Is the use of lead minimised in shielding design due to the material's hazardous classification and have alternate materials been considered (e.g. steel, water, concrete)?
- Has streaming through penetrations for piping, ducts, electrical conduits etc. been reduced by using shadow shields?
- Are penetrations positioned high in shield walls to minimise radiation levels in accessible areas as a result of primary and secondary radiation beam scatter?
- If shielding is not practical at installed locations, can equipment be moved to lower radiation areas for maintenance or inspections?
- Has shielding been provided for between individual components that constitute substantial radiation sources to help maintenance and inspection personnel servicing other specific components in the area?
- Has provision been made for transporting/storing radioactive components or sources using pigs or specialised shields?
- Does this engineering change affect components such that existing shielding calculations require review and/or change (e.g. pipe support removals, piping replacement)?

**For change involving surfaces which may become contaminated or measures to facilitate decontamination or contamination control, then:**

### *Section 5. Decontamination and contamination control*

- Are wall and floor surfaces sealed for ease of decontamination?
- Are surfaces that might become contaminated, non-porous, free from cracks, and sharp corners?
- Have measures been taken to reduce the spread of contamination from the source (curbing, slopes to drains, sumps etc.)?
- Are drainage provisions (including drain vents) made for all sample points to collect overflow and flushing water?

**For change involving material, construction or assembly techniques, shapes, flow patterns or choices of equipment in direct contact with systems containing radioactive material, then:**

### *Section 6. Source reduction, mitigation of radiation field build-up and crud control*

- Are components in contact with primary coolant comprised of low cobalt, nickel, manganese etc. alloys to minimise activation products that contribute to plant radiation fields? If "no", please explain why such alloys cannot feasibly be used.

- Do design features incorporate highly corrosion-resistant materials to minimise material losses to primary coolant?
- Are proper lubricants and favourable geometries utilised to prevent loss of material by erosion of load-bearing hard facings (typically Stellite) and subsequent entry into primary coolant?
- Have smooth surfaces been considered to reduce crud deposition?
- Are new systems or components chemically preconditioned to minimise the rate of corrosion product release and render surfaces less susceptible to deposition and incorporation of activated corrosion products?
- Have potential crud traps been identified and eliminated where possible? For example: Avoid crevices, dead legs, 90 degree turns and areas of low flow that can become crud traps.
- Have crud removal methods such as flushing, recirculation, hydrolysing, chemical decon or other means been incorporated to reduce personnel exposures?
- Are drains provided at low points in systems to flush out crud?

**For change involving valves containing radioactive fluids and/or related components, then:**

### *Section 7. Valves containing radioactive fluids*

- Do valves located inside high radiation areas have sufficient space for maintenance?
- Are full ported valves (opening inside valve same as pipe) used to prevent interference with process fluids during valve cycling and minimise crud traps?
- Have all relief valves and rupture discs in the area been considered for possible radioactive releases and subsequent replacement?
- Are valves designed in the stem-up position to facilitate maintenance and prevent crud traps (note: some valves require installation with stem oriented several degrees off the vertical for proper functioning)?
- Have valves designed with bonnet cavities been avoided?

**For change involving piping containing radioactive fluids and/or related components, then:**

### *Section 8. Piping containing radioactive fluids*

- Are radioactive systems designed to minimise dead legs, standpipes, and low points?
- Are large radius pipe bends of at least five pipe diameters used instead of elbows to reduce deposition or resins, sludge and crud products?

- Are pipe fittings, pipe bends, pipe tees and field welds minimised to reduce collection of radioactive material?
- Are butt welds used instead of socket welds to allow smoother interior system surfaces?
- If a tee is used in piping, is the normal flow through the straight portion and are branch lines located above the run?
- Are lines carrying spent resins or slurries run as vertically as possible?
- Are short runs of pipe used to reduce accumulations of radioactive materials?
- Are long runs of pipe sloped to minimise crud build-up?
- To reduce crud traps, are connections on piping made above the centreline?
- Are orifices installed in vertical piping runs where possible?
- Is piping diameter sized to preclude the need for orifices, maximise fluid velocity while minimising settling and to minimise line plugging?
- If pass-through piping may cause high radiation levels in an area during routine maintenance, has consideration been given to relocating the pipe or for providing shielding?
- Are all lines carrying spent resins or radioactive slurries designed without flow control valves or orifice?
- Can lines that are subject to plugging be back flushed or flushed with lower activity liquid?
- Has piping containing radioactive fluids been routed to take credit for shielding effects of equipment and structures?
- Are piping and hanger supports designed to adequately support temporary shielding?
- Has electro polished stainless steel piping been considered in order to retard radiation field build-up in out-of-core piping?
- Does design incorporate piping designed to contain radioactive material under both normal and off-normal conditions?
- Are hot tap clean outs with ball valves used in lieu of flanged connections where feasible?
- Is the flow in pipes other than sample and radioactive waste lines laminar to prevent crud or other radioactive material deposition due to eddying?
- Are systems containing radioactive slurries provided with check valves or strainers at interface with liquid systems?

**For change involving tanks containing radioactive fluids and/or related components, then:**

### *Section 9. Tanks containing radioactive fluids*

- Are tanks designed with sloping or round bottoms and/or spargers to remove radioactive sediments?
- Are tank drain valves located away from the tank bottom to minimise exposure?
- Are isolation valves on lines connected to tanks containing spent resins, sludge, or concentrates, located to minimise dead legs?
- Are all liquid radioactive waste tanks and floor drains provided with a vent collection system and are vents filtered to minimise collection of solids in the system?
- Have cleanout connections been provided on tanks?
- Are tank overflow lines directed to the radioactive waste collection system?
- Can air versus water spargers be used to prevent nozzle blockage?

**For change involving pumps containing radioactive fluids and/or related components, then:**

### *Section 10. Pumps containing radioactive fluids*

- Is seal water taken from contaminated sources avoided where possible?
- Has consideration been given to incorporation of seal less pumps?
- Are provisions made to drain pump casings or equipment?
- Is controlled leakage purge across journal sleeves used to avoid entry of particles into primary coolant?

**For change involving filter or filter systems in radioactive systems, then:**

### *Section 11. Filters in radioactive systems*

- Are screens or filters provided in vent lines from radioactive tanks and can they be replaced or cleaned easily?
- Are provisions made for remote removal and installation of filters where predicted dose rates are very high?
- Are gaseous effluent filters in areas large enough for remote handling tools and temporary shielding to be used?
- Are filters used throughout the system standardised and able to be back flushed?

**For change involving heating ventilation and air conditioning systems, then:**

### *Section 12. Heating, ventilation, and air conditioning which potentially contain radioactive effluents*

- Are welded seams employed in air ducts?
- Have high efficiency filters, electrostatic precipitators, and charcoal filters been considered to minimise the transport of radioactivity?
- Are high flow rates and temperatures maintained in HVAC systems prior to filtration?
- Have provisions been made to reduce localised airborne radioactivity by techniques such as leakage collection, ventilation and component selection?
- Is ventilation flow from areas of low potential airborne activity to areas of high potential activity?
- Is the number of directional changes in ductwork containing airborne radioactive material minimised to prevent contamination build-up?

**For change involving process instrumentation controls or sampling systems, then:**

### *Section 13. Process instrumentation and controls/sampling systems*

- Have instrument systems using intermediate fluids or fluid isolation been considered?
- Are instrument taps located above the midplane?
- Are local sample points minimised with piping or conduit routed to a central shielded location?
- Are sampling systems designed for high continuous purge flow for quick, accurate samples routed to shielded or remote locations, including accident conditions?

**For change involving radiation detection instrumentation or monitoring systems, then:**

### *Section 14. Radiation monitoring systems*

- Does electrical circuitry allow indication of detector failure?
- Are local alarms and readouts provided?

**For change involving new facility design or significant change to an existing facility, system or group of like components, then:**

### *Section 15. New facility design/significant design changes to existing facilities/systems*

- Have systems and components been segregated such that low, moderate and high radioactivity sections are separated and located with the corresponding systems or components to the extent possible?
- Have shielded chases been considered for high radiation piping, especially pass-through piping runs?
- Are valves shielded from high activity equipment by using valve galleries?
- Have skid-mounted systems been designed with shielding between high and low activity portions or adequate spacing to allow future addition of shielding?
- Are shield doors, shield plugs or labyrinths used to reduce exposure while ensuring ability to access and remove components?
- Is access control provided for in the design of new areas or change of existing areas?
- Are barriers provided to limit access to areas that are greater than 10mSv/h?
- Are proper equipment decontamination facilities available nearby to equipment, in low radiation areas?
- Are decontamination areas provided with lay down area for additional storage of equipment prior to decontamination?
- Are services such as electrical power, water, and air located reasonably close to radiation work areas?
- Is the system laid out to maximise the effective distance between radiation sources and work locations?

# *Appendix 2*

# ALARA engineering design principles

## 1. Assessing radiation doses

Radiation designs should provide for anticipated dose by including analysis of the tasks and processes that occur in these areas, the anticipated dose rates for the area and the proposed inventories of radioactive materials.

### *A. Workers and time*

Moreover, the numbers of workers and the amount of time they are expected to spend in the area should be taken into consideration.

For example, general (low-level) operations areas consist of those areas with small or moderate inventories of radioactive materials. Examples are general radionuclide research labs, rooms containing properly shielded X-ray diffraction and spectroscopy units, and operation areas with low contamination and low dose-rate potential.

Work in higher-level operation areas, however, typically involves more radioactive material than does work in general operation areas. Examples of process operation areas are glove box and hot-cell operating areas, control areas for high-dose rooms, and selected areas of accelerator facilities where experiments with moderate dose or contamination potential cannot be remote-controlled.

### *B. Multiple sources*

It is important in building layout to minimise simultaneous dose from multiple sources at locations where maintenance personnel may be required to work. Similarly, individual work stations should be shielded from one another if work by one individual may expose others in the same area to unnecessary dose.

### *C. Remote operations*

Functions in remote operation areas are usually remotely or automatically controlled. Occupancy in these areas is predominately for process monitoring or the adjustment of operations occurring in areas of high hazard and restricted access. Examples of this type of area are hot-cell service and maintenance areas and transfer areas where highly dispersible materials of high-dose rate are introduced into the process system or hot cell.

### *D. Isolation areas*

Isolation areas include areas with high-dose rates or airborne contamination levels. Unauthorised and unmonitored entry in these areas is forbidden, and design features shall prevent the unauthorised entry of personnel. All personnel are prohibited from entering when conditions in the area present an immediate hazard to human life. Physical controls are required to limit doses when these areas are occupied.

## 2. Access control considerations

Building layout is an important factor in controlling personnel dose by regulating the flow of personnel and material. Proper layout reduces casual or transient exposures to radiation fields by segregating heavily used corridors and the work areas of non-radiation workers from the areas of high radiation and contamination. The layout should effectively limit occupational dose to areas where the performance of an assigned task requires some degree of radiation dose. Controlled areas defined in Rule 10 CFR 835,[1] are addressed in Module 103. A general discussion follows.

### *A. Sequential areas*

An acceptable technique for achieving proper building layout is to establish a system of sequential areas. This concept is frequently used because it is adaptable to the physical control of external and internal dose equivalents. In addition, the design is an excellent precursor to planning and establishing operational radiation control areas.

### *B. General access and controlled areas*

Two major types of areas are included in any nuclear facility: uncontrolled areas and controlled access areas.

#### *General access*

General access areas are normally places to which public access is restricted but where direct radiation exposure is not necessary for job performance, such as the work areas of administrative and non-radiation support personnel. These areas include conference rooms, file rooms, clerical and other support offices, lunch rooms and rest rooms.

#### *Controlled areas*

Controlled areas are areas to which access is managed to protect individuals from exposure to radiation and/or radioactive material. Individuals who enter only the controlled areas without entering radiation areas are not expected to receive a total effective dose equivalent of more than 100 mrem (0.001 Sv) in a year.

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[1] US Department of Energy, Federal Register Vol. 58, No. 157, Rules and Regulations, 10 CFR Parts 820 and 835 (1993) and Vol. 72, No. 110 (2007).

Controlled areas may include corridors that are adjacent to, or connected with, areas that contain radioactive materials, change rooms, or special offices for radiation workers.

### *Radiation area*

Any area within a Controlled Area that meets the definition of a Radiation Area, Contamination Area, High Contamination Area, Airborne Radioactivity Area, or High Radiation or Very High Radiation Areas. For the purpose of access control, we can divide Radiation Areas into buffer areas (also called contingent areas) and areas of contamination or elevated dose rates.

### *Buffer/contingent areas*

Buffer areas should contain offices only if the facility design criteria specify that the offices must be near radiation areas. The primary functions of buffer areas are to control contamination and to isolate radiation areas from general access areas.

## *C. Traffic*

- Locate frequently used pathways in low-radiation areas and non-contaminated areas.[2]
- Plan transport routes inside and between buildings so that non-radioactive material does not have to pass through radiation areas and vice versa.
- Plan personnel traffic routes so that clean or general access areas are not isolated and do not have to be reached by passing through a radiation area.
- Plan personnel traffic routes so that access paths between contaminated areas do not pass through clean areas.
- Consider the sizes and locations of monorails, cranes, doorways, corridors and hatches in relation to the radiation or non-radiation areas they will serve.
- Be sure to consider the paths that fire-fighters will take in entering a radiation area. Try to provide paths that will keep them farthest away from areas of high-dose rate while providing adequate access to the most likely area for a fire.

## *D. Access*

- Provide adequate space around components for inspections and maintenance activities.
- Locate supports so as not to interfere with inspections and maintenance, and facilitate removal of equipment.

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[2] Use common sense and logic. If the pathway is in "clean areas" but in a long and illogical route, people will not use it and may take "short cuts" through hot areas.

- Provide space and rigging path so that equipment can easily be removed from areas of elevated dose rates for maintenance.
- Ensure that wide and large enough doorways and access areas are provided so that components can be easily removed for maintenance or inspection.
- Provide permanent platforms, rigging devices etc. for easy access to components in hard-to-reach places.
- Provide lay down space to allow equipment and components to be disassembled.
- Minimise the number of personnel access control points, and size and equip them for the expected number of workers who will use them.
- Areas with significant concentration of airborne radioactive materials should be provided with physical barriers to prevent the entry of unauthorised individuals.
- Provide one of the following features for each entrance or access point to high radiation areas:
  - A control device that prohibits entry when high radiation levels exist, or upon entry causes radiation levels to be reduced below High Radiation Area levels.
  - A device that prevents operation of the radiation source.
  - A control device that energises a conspicuous visible or audible alarm.
  - A locked entry-way. Or
  - Continuous surveillance capable of preventing entry.

Additionally, very high radiation areas must prohibit entry when dose rates are greater than posting requirements.

- Provide panic exit bars on the insides of locked doors as well as locks, alarms and interlocks as appropriate for areas requiring them.
- Provide space for temporary access control points where it is anticipated they will be needed from time to time.
- Provide space, support and electrical hook-ups for personnel contamination monitors as needed at each access control point.

## *E. Radiation areas*

- Make contamination and radiation areas as small as possible.
- Provide for posting of radiation areas and anticipated hot spots.

## 3. Contamination control design considerations

### *A. Contamination control*

- Slope floors toward sumps or floor drains and use curbs, dikes, berms and trenches as appropriate to remove leakage promptly.
- Hard-pipe drains, tank overflow, valve stem leakage etc. to sumps.
- Route drains directly to proper radioactive waste sumps or tanks.
- Provide stainless steel collection pans as needed and direct leakage to drains via tubing or piping (stainless steel resists corrosion and facilitates decontamination).
- Always consider whether flooding (due to leakage, back up of a sump etc.) may cause the contamination of equipment, and elevate such equipment above flood levels.
- Use raised sleeves in floor penetrations; consider sealing the penetrations or providing a hood.
- Avoid using open gratings for stairs or platforms in potentially contaminated areas.
- Provide space and support for the use of glove bags and other containments over the space created when the head of a heat exchanger is removed, or where a pipe is opened, and in similar cases.
- Allow room inside and/or near contaminated or potentially contaminated areas for friskers, step-off pads and used protective clothing bins.

### *B. Decontamination*

Plan for eventual decontamination: if decontamination is done in place, the worker may experience a high-dose rate from other equipment in the area; he may not have much room to work in; and the decontamination fluids, cloths, and removed parts will have to be collected. If the equipment is removed for decontamination at another location, it may have to be bagged up, lifted, loaded, and moved along a path, possibly passing through general access areas or areas of narrow clearance.

There are several ways to facilitate decontamination during the design phase:

- Provide smooth, nonporous and nonreactive surfaces on equipment (inside and out), floors, insulation, walls, trenches, doors, plugs and tools.
- Make generous provisions for services to be used for anticipated decontamination: water, air, electricity and other connections.
- Provide cleanout openings, taps for hydrolasing or chemical "decon" hatches, collection pans and means for flushing and draining (be aware that the cleanouts are themselves a crud trap).

- Consider a central decontamination station for a large facility or operation; size, equip and locate it for the types, sizes, number and locations of the equipment it is to handle.

## 4. Radioactive waste considerations

### A. Temporary radioactive waste storage

- Location for the temporary storage of radioactive wastes must be designed into both the building plan and the plan for each area where radioactive materials are handled.
- Radioactive material handling areas should be designed with a special area for waste accumulation. This area should be removed from the generally occupied areas of the facility.
- Special attention should be paid to fire prevention, spill control and (if necessary) vapour or odour control.

### B. Bulk radioactive waste storage

- Operating areas should not be the principal areas for interim bulk waste storage. Instead, all major facilities should be designed with a special bulk storage area.
- This area should be located so that wastes being removed from the building will not have to be transported along major personnel traffic routes or through uncontrolled access areas.
- To prevent accumulations of waste in operating areas if normal disposal methods are temporarily interrupted, the waste storage area should be large enough to accommodate more than the expected volume of waste.

### C. Transport

- Plan routes over which solid and liquid wastes in containers must be transported to avoid general access areas as much as possible.
- Minimise distances over which moderately and highly radioactive wastes are transported from operating areas to disposal points.

### D. Drainage of liquid systems

- Design drain basins, curbs and catch or retention tanks for efficient and complete drainage.

### E. Monitoring

- Install monitoring systems to detect any leaks or spills in areas where drainage or retention is unattended or is remote controlled.

### *F. Fire suppression*

- Install fire-suppression systems in areas where combustible radioactive material may accumulate or be stored. Consider the effects of fires not only in the radiation areas, but also in the non-radiation areas.

## 5. Shielding, penetrations and routing considerations

### *A. Shielding*

- Obtain information on shielding types, thicknesses and layout from a radiation specialist (a radiation engineer, ALARA specialist, or health physicist, as appropriate for your project or operation).
- Do not be reluctant to ask if another type of shielding will do, or if there is a way to accomplish what you want without so much shielding.
- Labyrinth entrances should be considered for some radiation areas, and for all high radiation and very high radiation areas.
- Take into account the build-up of the source or other source accumulation over the years (install more shielding than is immediately necessary, or provide space and support for shielding to be added later as the source builds up).
- Consider removable shielding, such as block walls and ceiling hatches for large equipment, but remember that the removal and re-emplacement will cost some dose. Use proper overlapping and stepping in the design and emplacement of such shielding.
- Consider temporary shielding when it would be needed only briefly or infrequently (allow for space, support and transport requirements).
- Consider special shielding such as shield doors, leaded glass windows, covers for hot spots, transport casks and shielded carts or forklifts.
- Add permanent hooks, latches, fasteners and structural supports to secure temporary shielding.
- Design shielding to separate components used for processing or storage of radioactive materials to allow for routine operations and maintenance.

### *B. Penetrations*

- Have experts from all affected disciplines review a planned penetration before the hole is made.
- Minimise the size and number of penetrations (several small penetrations are usually better than one big one).
- Place penetrations in the thinnest shield wall, near a corner, as high up as possible, and not in a line of sight with a source.

- Place penetrations so they do not line up with accessible areas, including stairways, doorways and elevators.
- Place penetrations so they do not line up with any radiation-sensitive equipment, such as electronics, attached to a wall or ceiling on the low-dose-rate side of the penetration.
- Consider offset penetrations.
- Provide labyrinths or shadow shields behind penetrations to reduce streaming or scattering through the penetration.
- Seal penetrations, where justified, for dose-rate reduction, air-flow control and leakage control.

### *C. Routing of ducts, pipes, cables and conduit (DPCs)*

- Have DPCs enter through a labyrinth or door, if possible.
- Do not route DPCs containing contaminated fluids through general access areas, or clean DPCs through potentially contaminated or high-dose-rate areas. Locate connections, pull spaces, junction boxes, panels, valve operators and taps in low-dose-rate areas or at least on the low-dose-rate side of the wall. Provide as short a run of sample and other potentially contaminated lines as possible into the accessible areas.
- Do not regard the X-Y-Z grid as sacred. Minimise runs of piping by routing diagonally, using bends other than 90 degrees, and sloping lines.
- Route clean and radioactivity-containing pipes in separate areas, especially pipe tunnels. A worker servicing clean systems should generally not receive significant dose.
- Route to provide adequate clearance for maintenance, inspection and insulation.
- Do not field-route radioactivity-containing DPCs (if it is necessary, guidance should be given to the routers as to the path and areas in which the pipe may go).
- Make as-built drawings of field-routed piping to ensure that lines containing radioactivity are known and identified.

## 6. Equipment separation, segregation, placement and isolation considerations

### *A. Separation*

- Put shield walls between components sharing the same cubicle to reduce the dose to a worker maintaining one of them (the equipment should be placed so that the worker does not have to pass close to one to get to the other).
- Separate passive equipment, such as tanks, from active or frequently maintained equipment with shielding.

- Consider multi-skid designs for appropriate pieces of equipment to allow interstitial shielding (*e.g.* place shielding between pumps and their motors in highly radioactive streams because the pumps get "hot" while the motors do not).

## *B. Segregation*

- Segregate highly radioactive equipment from moderately radioactive equipment, and both from clean equipment. Similarly, segregate equipment with high airborne potential from equipment with less airborne potential, and both from clean equipment.
- Segregate radioactive equipment of different systems so that both systems will not have to be flushed, drained, or decontaminated to reduce the dose when only one needs maintenance.

## *C. Placement*

- Even with shielding, lay out equipment in an area or equipment cubicle so that the worker enters, progresses from low-dose-rate areas to moderate to high-dose-rate areas, and from active to passive equipment.
- Place inspection, control, and readout devices and panels in low-dose-rate areas.
- Place services (demineralised water, electricity etc.) near entrances or at least in the lowest-dose-rate areas.

## *D. Isolation*

- Properly place isolation valves to minimise dead legs.
- Minimise pipe runs in valve aisles (consider reach rods and valve operators).
- Thoroughly review any proposed interconnection between systems of different radioactivity potential (consider having only temporary connections between radioactive and clean systems, such as the demineralised water supply).

## *E. Redundancy*

- Provide adequate redundancy and back up capability, especially in systems of high radioactivity content and safety systems. Provide appropriate cross-connections to achieve this.

## 7. Accessibility, lay down and storage considerations

### A. *Accessibility*

- Allow adequate working space around major components, usually at least 3 feet. Do not allow this space to be filled by reach rods, shields, pipes, scaffolds etc.
- Provide more space if many workers or large tools are necessary for maintenance, and consider the space taken by protective clothing and respirators.
- Size labyrinths and doorways to allow the passage of workers, carts, forklifts and tools.
- Provide cranes or monorails for large pieces of equipment, pad eyes or anchor points for smaller ones, and lifting lugs on all components of significant weight.
- Consider permanent galleries or scaffolding where maintenance is frequent or prolonged; provide space and attachments for temporary structures where it is not.
- Select tanks that have manways sized for a worker wearing a full set of protective clothing, including respirator (preferably at least 24 inches).
- Supply adequate access around welds by providing prescribed separation between welds and between welds and penetrations.
- Minimise the number of stops, hangers, supports and snubbers, and orient them to maximise access space in the area.
- Consider sectional or modular design (*e.g.* snap-on segments of insulation on heat-traced lines that require frequent maintenance).
- Provide space for removal of filters into plastic bags or shielded containers.

### B. *Lay down and storage*

- Provide lay down space in a low-dose-rate area (besides equipment, consider such items as tool boxes, carts and hoses).
- Store hot tools (fixed contamination) and tools waiting for decontamination in appropriately posted, locked, shielded and ventilated areas.
- Properly store nonradioactive items to be used in radiation areas, such as dosimeters, filters, insulation and so forth, so that they will not be degraded by radiation, light, moisture etc.

## 8. Snubber, strut, hanger and anchor considerations

- Locate and design snubbers, struts, hangers and anchors so as to facilitate removal and replacement.

- Locate snubbers, struts, hangers and anchors so as not to interfere with inspections and maintenance.
- Replace snubbers with struts or energy absorbers whenever possible.
- Paint and tag snubbers, struts, hangers and anchors to facilitate location for repair and inspection.

## 9. Human factors

### *A. Consider visual factors*

- Make sure that signs, indicators, readouts etc. are clearly legible from a reasonable distance away.
- Avoid the use of nonstandard lettering.
- Provide adequate lighting and consider auxiliary lighting where equipment is located in a corner or behind other equipment, or where remotely operated cameras are used (provide automatic emergency lighting in areas where the dose rate may be elevated).

### *B. Consider auditory factors*

Provide alarms numerous and loud enough to be heard everywhere in the subject area. Also minimise background noise.

Provide adequate communications measures, especially in areas where maintenance and inspection workers or health physics technicians may need to communicate with their supervisor or health physicist during a job.

### *C. Consider human physical characteristics*

- Familiarise yourself with an appropriate reference on human sizes and physical capacities and apply this guidance to all design and operations work.
- Consider the use of lifting devices and special tools so that fewer workers can accomplish a job.
- Consider the effects of heat stress, particularly with protective equipment such as respirators and/or non-porous protective equipment.
- Consider provisions for lifelines to pull accidentally injured or unconscious workers from tanks, pools, or other areas of high dose rates or high airborne activity.

### *D. Help prevent human error*

- Make permanent alignment marks on the equipment or floor.
- Colour-code tools, conduit, bolts and pipes.
- Place identification on insulation to show what is underneath it.

- Clearly mark system line-up indication of valve position, breaker settings etc. near controls or equipment.
- Locate valves, valve operators, controls etc. in a logical manner.
- Consider automation of operational sequences, or use interlocks and warning lights for dangerous choices in manual sequences (also use interlocks as an aid to memory, such as automatically starting sample hood HVAC when the sample draw starts).
- Make it cheap in terms of dose for operations to be accomplished safely (*e.g.* in areas where the "buddy system" is used for safety, provide a low-dose-rate area where the watcher can observe, perhaps in the labyrinth entrance with a mirror).
- Consider providing mock-ups and simulators on which operators can practice for long or complex jobs.
- Special tools or equipment specific to one area should be provided and kept near that area.

## 10. Operations, maintenance and inspection considerations

### *A. Operations*

- Provide adequate space around components, permanently installed platforms, lighting, ladders, outlets etc. for operation of equipment.
- Locate remote operators or reach rods on high-dose-rate valves outside contaminated areas.
- Locate instrument readouts in low-dose-rate areas and away from contaminated areas whenever possible.
- Provide for operations and surveillance from outside a High Radiation Area through the use of remote readout devices, viewing ports, radiation detector ports or TV cameras.
- Provide access to equipment or instruments requiring frequent manual operation or surveillance via areas with the lowest possible dose rates.

### *B. Maintenance*

- Provide adequate space around components, permanently installed platforms, lighting, ladders, outlets etc. for maintenance.
- Select the components or systems with long service life, ease of maintenance, reliability, and operating record of low maintenance frequency.
- Ensure components requiring frequent maintenance (*e.g.* small pumps and valves) are designed to permit prompt removal (*e.g.* flanged connections) to facilitate repairs in low dose-rate areas.

- Eliminate or minimise periodic maintenance items (*e.g.* O-rings, gaskets, packing, protective coatings and lighting components).
- Consider using lubricating systems or self-lubricating units.
- Provide a mechanism to allow rigging of the component (*e.g.* pad eyes).
- Provide access to equipment and components requiring frequent maintenance via areas with lowest dose rates practicable.
- Ensure that the valve maintenance procedure controls stellite filings to reduce cobalt where neutron activation of the stellite is possible.
- Design and orient components to minimise crud build-up.

### C. Inspection

- Provide adequate space around components, permanently installed platforms, lighting, ladders, outlets etc.
- Ensure that insulation design allows for rapid removal and replacement (*e.g.* match marks, fibreglass blankets).
- Locate equipment with consideration given to facilitating inspections required by Section XI of the ASME Code, Appendix J, Appendix R, and other inspection requirements of the ISI leak rate and fire protection programmes.
- Provide visible tags and levels to identify equipment, snubbers, welds, penetrations, valves and other items requiring inspection.
- Locate access to equipment or components requiring frequent inspections via areas with lowest possible dose.

# *Appendix 3*

# Application of ALARA to facility system design

## 1. Airborne radioactivity and HVAC system considerations

Ventilation systems deserve separate ALARA considerations because of the possibility of increased doses due to internal uptake of airborne and surface contamination. Routinely requiring workers to wear respiratory devices is not the preferred solution to reducing internal deposition of airborne radioactive materials.

The facility ventilation system(s) are a major means for controlling airborne radioactivity levels in occupied areas under both normal and abnormal conditions.

### *A. Essential features*

Ventilation systems have two tasks: to direct airborne radioactivity away from personnel and to provide an adequate method to capture (in some cases, and/or monitor) any airborne radioactive materials that are released. To attain these objectives, ventilation systems usually incorporate two essential features:

- Appropriate differential pressure (DP) between ventilated areas and outside areas.
- High-efficiency particulate air (HEPA) filtration.

### *B. Area-specific requirements*

Similar areas do not always require identical ventilation characteristics, especially differential pressure and filtration. Ventilation design criteria need a measure of flexibility since conditions may change as work changes and since local or portable ventilation may be effective at reducing local airborne radioactivity levels significantly.

### *C. Eliminate/reduce airborne sources*

To ensure control of airborne radioactivity, design for the following as appropriate:

- Properly seal and pressurise equipment and ducts with continuously welded seams and flange gaskets.

- Leak-test HVAC equipment after installation and repair.
- Select filters appropriate to the operation and radionuclides present (*e.g.* charcoal filters are good for iodine, but they do not last as long if they get loaded with non-radioactive particulates and dust; you may also need a prefilter for dust and/or a HEPA filter for particulates).
- Provide differential pressure detectors across filters to monitor dust loading.
- Avoid open-topped tanks or tanks with vent lines lower than tank overflow lines.
- Generally avoid hard-piping tank vents directly to ducts if the tank may become pressurised.
- Use good contamination control practice in designing for such tasks as filter change-out, wet layup of equipment and machining contaminated parts.
- Use water for back flushing and unplugging in preference to compressed gases.
- Properly place and seal penetrations, gratings, openings etc., which are open to areas of potential airborne radioactive materials.
- Specify sealed bearing motors with the motor mounted external to the exhaust.
- Provide intake air filters to minimise exhaust filter loading and dust accumulation in radiation areas.
- Provide drains and/or dryers and/or moisture separators upstream of filters and charcoal beds.
- Provide auxiliary or temporary ventilation systems for sampling stations used to sample highly radioactive fluids (*e.g.* reactor primary coolant) and for repair of equipment that when opened, has a potential for airborne releases (consider both temporary ductwork attached to existing systems and independent, portable HEPA-filtered ventilation systems).

### *D. Air flow*

A system of differential pressure should be used to direct the flow of any airborne radioactive material that escapes containment.

- Room air may be re-circulated if adequate filtration and monitoring are provided.
- Direct air flow from areas with no or less potential contamination to areas with greater potential for contamination.
- Primary confinement shall always have the least pressure in a facility (relative to the outside atmosphere).

- A gradient should be established, on a facility and room basis, so that the lowest pressure and exhaust collection points are located in areas with potentially dispersible material.
- Ducts carrying potentially contaminated air should be at a negative pressure when passing through a clean area.
- Locate ventilation supply points above the worker or work area and away from the sources of contamination, or otherwise place as appropriate for the work activity (*e.g.* for work tables, glove boxes and hoods).
- Avoid drawing contaminated air across walkways, doorways, entrances, work areas and, especially, breathing zones.
- Locate ventilation exhausts near the floor and away from entrances or openings to clean areas.
- Locate ventilation fans as close as possible to the discharge, downstream of filters so as to avoid contaminating the fans and pressurising the filters.
- Exhaust through a filtration system from areas with greatest potential for contamination.
- Minimise the number of elbows in ventilation ducts to reduce the plate out of radioactivity and to reduce flow losses. Alternatively, consider flow straighteners.
- Size ducts and fans to have high enough flow rates to reduce plate out.
- Select smooth materials or consider coating inner surfaces to reduce plate out.
- Ensure that the opening of doors and removal of shield plugs does not disrupt proper air flow.
- Provide connections to attach temporary ventilation systems where additional ventilation flow may be needed.
- Design ventilation so as to minimise the use of respirators.
- Use airlocks where appropriate.

### *E. Filtration systems*

- Select proper type, size and quantity of air filtration devices.
- Locate filters as close to the source as possible and upstream of any fans to reduce contamination build-up in ductwork and fans.
- Provide roughing filters upstream of HEPAs and HEPAs upstream of charcoal filters.
- Provide flushing ports and drains for decontamination of filter housings and ventilation ducts.

- Place filters for highly contaminated ventilation systems in shielded housings and locate filter banks in low-occupancy areas.
- Design filter housings and filters so that filters can be removed remotely or quickly in the event of an incident.

### *F. Maintenance*

- Design ventilation systems for ease of maintenance, inspections, testing and operations.
- Locate ventilation motors in low-dose-rate areas whenever possible.
- The proper design of the ventilation system permits filters to be changed easily and with a minimum potential for the release of radioactivity and worker exposure.
- The design shall provide the capability for in-place testing of the filtration system.

### *G. Monitoring*

- All airborne and potentially airborne radioactivity areas shall be vented to a monitored release point.
- The design should allow for continuous particulate sampling before the first testable stage and after the last stage, to provide direct evidence of filter performance.
- Areas with a high potential for airborne radioactivity may require sampling between intermediate stages to verify the performance of each stage.

### *H. Emergencies*

- Key ventilation systems in a radiation facility must be provided with emergency power to assure continued operation if normal power is lost.
- Ensure adequate air flow throughout the area to provide quick cleanup of air during spills or leaks.

## 2. Containment considerations

### *A. Containment*

A containment is an area enclosed by a set of barriers. These can be passive barriers, like walls, or active barriers, like valves and ventilation flow.

- The primary containment is the barrier or set of barriers most intimately in contact with the radioactivity.
- The secondary containment encloses the primary and receives and handles any leakage from it.

- A tertiary containment may also need to be provided.

One constraint on defining these is that it usually must not be possible for a single failure to compromise two containments at once (*e.g.* a primary and its secondary).

### B. Primary containment

Containment is a way of thinking about a system configuration at a given time or in a given mode of operation, as well as having a physical meaning. For example, for a tank containing radioactive liquid, the tank itself is the primary containment, together with its intake and outlet piping up to the nearest isolation valves. When these valves are open, the primary containment extends to the next valve and so on. Also, a tank farther along may be a separate primary containment but can be considered, while the valves between it and the first tank are open, to be an extension of the first tank and, therefore, part of a single primary containment.

### C. Secondary containment

The room(s) or vault enclosing the tank and piping are the secondary containment and should be so designed; the outer wall of a double-walled tank may be the secondary. The building itself may be the tertiary containment.

### D. Glove boxes

Glove boxes and other handling enclosures are primary containments when radioactivity in them is not completely enclosed or is enclosed in containers that cannot be assumed to be well sealed. Glove boxes are secondary containments when the radioactivity is actually contained in a piping system, vessel, instrument etc., inside the box. In the latter case, the room may be designed as the tertiary containment.

### E. Primary containment penetrations

Primary containment penetrations must be carefully laid out and minimised in number and size. They should be carefully sealed with regard to radiation streaming, air-flow control, fire protection and flooding as applicable. Permeation of these seals should be considered. Transfer ports for passing items in and out should, in general, be airlocks or mini-airlocks, with purging capabilities.

### F. Isolation systems

A principle of good confinement is good isolation; systems with widely differing levels of actual or potential radioactivity content should be isolated from one another by check valves or other reverse-flow control devices. Pressure relief devices should be required, and leak detection devices should be provided as appropriate to the process.

### *G. Check valves*

Check valves on tritium systems leak when closed and do not provide good confinement.

Because check valves have problems, they are often used in pairs. Their good points cause them to be extensively used, but they must be used wisely.

## 3. Mechanical systems considerations

This section discusses six areas: piping, valves, pumps, filtration, tanks and heat exchanger systems.

### *A. Piping and tubing*

The following guidance should be applied in piping and tubing design.

#### *1. Eliminate/reduce radiation sources*

- Route piping to minimise the length and number of pipe fittings and bends.
- Tee branch piping above the main flow piping or slope the teed branch upwards.
- Design piping to avoid dead legs and minimise tees.
- Provide a continuous slope on the piping to prevent backflow and settling of crud.
- Provide smooth surfaces to avoid crud traps and facilitate decontamination and flushing.
- Use materials with low nickel and cobalt content for reactor facilities or other facilities where neutron activation may occur.
- Route piping carrying highly radioactive fluids away from equipment requiring frequent maintenance.

#### *2. Eliminate/reduce contamination sources*

- Segregate radioactive and non-radioactive piping.
- Provide adequate controls to prevent and/or detect cross-contamination of clean non-radioactive systems.
- Plumb pipe and leakage to floor drains and vents to ventilation ducting, where possible. But beware of pressurisation that may send liquid or solid materials out of vents.
- Select piping and components that will maintain containment over the environmental qualification range to prevent release of radioactivity to the offsite environment.
- Avoid the field routing of piping that transports radioactive materials.

### 3. *Maintenance*

- Select low-dose-rate areas for installation whenever possible.
- Provide adequate vents and drains to allow for system testing, maintenance and operation.
- Use consumable inserts for welding in lieu of backing rings for pipes carrying radioactive materials.
- Use butt welds rather than socket welds for pipes >1.5 inches. If a choice of welds is given in the welding specifications and if it is for a highly radioactive system, use a butt weld.
- Specify pipe bends of at least five pipe diameters in radius for the transfer of resin and sludge.
- Provide remote methods to unclog drain lines.
- Specify removable pipe insulation in areas where welds require in-service inspection.
- Provide connections on piping and components to allow flushing, hydrolysing or chemical decontamination on piping that contains resins, sludge or highly radioactive fluids.

## *B. Valves*

Since operation and maintenance of valves are two of the major contributors to workers' dose, the design engineer should apply the following guidance:

1. Eliminate/reduce radiation sources
   - Install valves with stems in the upright position to minimise crud build-up.
   - Select valves with internal surfaces and configurations that minimise crud build-up.
   - Use materials with low nickel and cobalt content for reactor facilities or other facilities where neutron activation may occur.
   - Provide steps in installation procedures to control stellite filings that are in valve internals (*e.g.* dams and/or vacuuming after grinding for reactor facilities or other facilities in which neutron activation may occur).
2. Eliminate/reduce contamination sources
   - Provide packing and seals that result in minimal contamination leakage and maximum reliability.
   - Consider packless valves or those using live-loaded packing; valves above 2.5 inches should generally have double packing and a lantern ring.
   - Locate valves away from low points in piping.
   - Provide check valves to prevent radioactive fluid back up.

- Provide catch pans, floor and equipment drains, or curbing under valves that have a significant potential for leakage.
- Separate valves carrying highly radioactive fluids from associated equipment and components.
- Consider future decontamination when providing isolation valves for fluid systems.

3. Maintenance
    - Select valve materials that are compatible with contact materials.
    - Locate valves in low-dose-rate areas whenever possible.
    - Provide remote operators or reach rods for valves located in areas of elevated dose rates.
    - Locate valves in an area with adequate work space to provide easy maintenance, inspection and operation.
    - Consider maintenance requirements on valves, operators and reach rods (e.g. select those that are easily removed).
    - Generally provide flanged connections on valves that may require removal from the radiation areas (e.g. pressure relief or isolation valves) however, welded connections may be preferable in some cases.
    - Provide rigging and lifting points for heavy valves requiring removal for repair or inspection.

### *C. Pumps*

Pump design should include the following considerations:

1. Eliminate/reduce radiation and contamination sources
    - Provide a mechanism to flush seals on pumps carrying highly radioactive fluids.
    - Install catch pans or curbing around pumps that transport radioactive fluids and have a significant potential for leakage.
    - Provide drain connections on pump casings as well as smooth surfaces on impellers.
2. Maintenance
    - Consider maintenance requirements on pumps, such as access and pull space for the motor shaft.
    - Provide rigging and lifting points for heavy pump parts requiring removal for repair or inspection.
    - Provide flange connections to facilitate removal of pumps located in areas of elevated dose rates to facilitate removal.
    - Select pumps with mechanical rather than packing seals (canned-rotor pumps or magnetic-driven pumps).

## *D. Filtration*

Maintenance, inspection and operational requirements for filtration/cleanup systems as well as shielding and isolation of highly radioactive systems must be considered.

### *1. Eliminate/reduce radiation sources*

- Provide filters upstream of deep-bed demineralisers to extend resin life and thus reduce radioactive waste volume.
- Provide strainers downstream of filters and demineralisers to entrain stray fines.
- Lay out demineralisers and resin storage components to assist resin flow and minimise piping (straight runs of piping with a minimal number of elbows).
- Provide filters and strainers that are back-flushable.
- Provide back-flushing capabilities sufficient to relieve plugged lines in resin slurry piping.

### *2. Eliminate/reduce contamination sources*

- Provide containment or ventilation to prevent spread of contamination during filter, strainer and resin changes.
- Provide screens, filters or other catch devices over resin, or sludge overflows and vents.

### *3. Dose rate*

- Isolate or shield filtration systems that contain high radioactivity.
- Locate filtration systems in low-occupancy and low-traffic areas.

### *4. Maintenance*

- Ensure that filters, strainers, evaporators, ion exchangers and routinely serviced items are compatible with existing equipment.
- Ensure that filters, strainers and evaporator tubes are easily removable and that adequate space is provided.
- Provide space for pallets to support temporary decontamination equipment that chemically cleans the system.
- Provide remote methods for draining filter housings on systems processing off gas and radioactive water.
- Provide remote and/or shielded methods for replacement of hot filters, strainers and resins.
- Provide flush connections that will facilitate high-velocity chemical flushes.

## *E. Tanks, sumps and floor and equipment drains*

### *1. Radioactive material handling equipment*

- Choose radioactive material handling equipment carefully. Consider decontamination and eventual decommissioning. Apply the following design guidance.
- Never undersize a tank used for holding radioactive material.
- Select tanks with sloped or dished bottoms to facilitate flow/draining and to eliminate corners as potential low-flow areas where crud may accumulate.
- Install top mixers, spargers or spray systems as appropriate to mix the contents for transfer and representative sampling, and for decontamination prior to inspection or maintenance.
- Ensure overflow lines are lower than the tank's vent.
- Provide screens or strainers on tank vents and overflow for tanks containing resin or sludges.
- Provide a slope from tank, drain and sump bottom to outlet.
- Provide curbing or other containment to restrict spread of leakage.
- Locate radioactive material tanks and sumps in low-occupancy and low-traffic areas or shield to reduce personnel dose.
- Locate tanks containing high radioactivity in shielded tank farms or cubicles.

### *2. Transfer systems*

- Prevent plugging in transfer systems.
- Avoid long vertical runs ending in a turn to the horizontal, which may lead to plugging.
- Reduce crud deposition by using pipes with at least 1-1/2 inch diameter, long bend radii, no right-angle bends and sloping runs.
- Provide turbulent flow to maintain homogeneity and keep solids in suspension.
- Choose full-ported valves when the fluid has high solids content.
- Consider automation of valve operation so that flow does not stop after a backwash or pre-coat.
- Provide a "recirc" line to ensure good mixing before transfer.
- Interior surfaces should be smooth and free of pockets to facilitate transfer and decontamination.
- When transporting liquid radioactive waste by pipes, the pipe route should be isolated from uncontrolled areas.
- Locate transfer lines in low-occupancy and low-traffic areas.

### *3. Maintenance/decontamination*

- Provide adequate space for maintenance and repair of tank support equipment (*e.g.* pumps, agitators, gear boxes etc.)
- Select preferred cleaning methods. Hydrolasing is preferred to air blowout, which is preferred to rodding out. Screens or filters should be provided when using air blowout. Stringent contamination control measures should be used during rodding out.
- Avoid lap joints and backing rings on welds.

### *F. Heat exchangers, moisture separators and heaters*

Modifications or replacement of heat exchangers carrying radioactive fluids should consider the following:

1. Eliminate/reduce radiation and contamination sources.
    - Provide drains at low points to facilitate flushing and cleaning.
    - Design vessels to reduce crud traps in those areas that require access during inspection and cleaning.
    - Select the proper material for the operating environment to minimise corrosion (*e.g.* titanium tubes for brackish water).
    - Orient heat exchangers in the vertical position, where feasible, to reduce deposition along the length of it.
    - Maintain radioactive fluids at lower pressures to ensure that leakage would be from the non-radioactive side into the radioactive side.
    - Provide curbing and drains to contain radioactive fluids during repair and cleaning.
2. Dose rate.
    - Pump fluids with the higher concentration of radioactivity inside the tubes to utilise the water in the shell as shielding.
    - Place heat exchangers that are expected to be highly radioactive inside shielded cubicles.
    - Provide adequate space to allow for removal and cleaning of the tubes and shell.

## 4. Electrical power system consideration

The ALARA design considerations that follow are geared toward the power systems engineering discipline.

### *A. Routing/Location*

- Perform walk downs or utilise photographs in low-dose-rate and low-interference areas to aid in locating conduit runs.
- Route cable and conduit in low-dose areas.

- Evaluate routing of electrical cabling through potentially contaminated areas in light of installation doses and accessibility requirements.
- Locate breaker boxes, power control centres and electrical cabinets in low-dose rate areas.
- Physically separate local control and alarm stations from associated electrical equipment located in areas of elevated-dose rates.

### *B. Maintenance*

- Select long-life bulbs to decrease maintenance time in radiation and contamination areas.
- Select electrical equipment with features that minimise inspection, calibration, testing and preventative maintenance (*e.g.* quick disconnects).
- Select high-quality electrical equipment with proven reliability records and low maintenance requirements.
- Provide external access for fault location determination capability for those electrical systems that are difficult to inspect or troubleshoot.
- Prefabricate conduit, supports, brackets, cable trays, junction boxes and other electrical components to be installed in areas of elevated dose rates.
- Provide sufficient electrical outlets for air-sampling devices.
- Provide adequate lighting as well as provisions for supplemental temporary lighting.
- Ensure that the conduit and electrical equipment do not interfere with the maintenance or operations of nearby equipment.

## 5. Sampling, monitoring and instrumentation

### *A. Sampling*

It is important that the sample is representative of the material sampled with respect to location, physical state and chemical composition.

Therefore, avoid having the sample deposit inside sample lines and equipment because it and subsequent samples might then be unrepresentative. The design engineer should apply the following guidelines to ensure representative sampling.

Follow the guidelines for reduction of crud deposition, especially considering the reactivity of the line material with the sample. For example, plastic piping may be best in many cases because of low-chemical reactivity but may not be suitable for airborne particulates due to static charge build-up.

- Provide sample lines that have few bends. Any necessary bends should have a large radius and be able to be isolated and flushed.

- Provide a strong and continuous purge of sample lines in high-radioactivity systems.
- Consider very carefully the proper flow velocity in the system, given the physical and chemical characteristics of the stream.
- In gaseous systems, ensure continuous flow or well tracked flow (consider flow meters, totalisers, constant-flow regulators and recorders).

### *B. Sampling station*

The following design criteria are applicable to radioactive material handling areas.

- Make sure any ventilation hoods have a face velocity of 100-150 linear feet per minute with the hood window in its full open position.
- Direct ventilation hood exhaust to the facility vent upstream of the filters.
- Route any sink drains in sampling or radioactive material handling areas to radioactive waste or retention tanks. Sinks should be free of any potential crud traps.
- Construct or coat sinks and surfaces of sampling areas with materials that are easily decontaminated.
- Separate or shield sampling stations from other radioactive components.
- Provide adequate shielding or separation for high dose rate activities.
- Minimise potential for cross-contamination of non-radioactive systems.

### *C. Monitoring*

Sufficient and carefully chosen radiation and air monitors should be provided to cover all areas where there is a potential for dose rates or airborne concentrations to exceed the limits of the respective areas. The design engineer should apply the following guidelines for the selection and location of monitors.

- Make sure that there are no obstructions or blocking of any monitor.
- Provide methods to perform remote sampling and monitoring for airborne radioactivity, where appropriate.
- Locate process and effluent monitors to provide enough detection lead time so as to divert or isolate a process stream, if that is their function.
- Provide manual friskers, portal monitors and half-body contamination monitors in suitable locations. Be sure to provide services for them; for example, gas-flow proportional counters need room for its gas bottle and, perhaps, storage for another nearby.

- Make sure that all airborne monitors are able to detect 8 DAC-hours (under laboratory conditions) as recommended by the Radiation Control Standard.
- Make sure that all monitors have circuitry that automatically can detect monitor failure and indicate whether the dose rate is off-scale.
- Provide readouts and alarms that are local, remote, or both, as appropriate (make sure the alarms are both visible and audible where required).

### *D. Instrumentation*

- The ALARA design considerations that follow apply to the instrumentation and control systems disciplines.
- Select instruments that contain minimal quantities of contaminated working fluid and isolate whenever possible by choosing pressure transducers over bellows type instruments.
- Follow good practices for crud deposition reduction.
- Locate instrument tubing taps on the top half of instrument lines carrying radioactive fluids.
- Locate all instrumentation, except for primary sensing elements, in low-dose-rate areas and provide for in-place calibration from low-dose-rate areas.
- Locate pagers, telephones and other communication systems in a low-dose-rate area.
- Ensure instruments that must be located in areas of elevated dose rates are easily removable for remote repair and calibration in a low-dose-rate area.
- Provide remote viewing of local readout instruments.
- Select instruments with features that minimise inspection, calibration and testing functions.
- Select high quality sensors with proven reliability records and low maintenance requirements for monitoring systems.
- Provide for logical groupings of readout instruments to decrease time needed for surveillance and logging.
- Consider using computers for automatic logging.
- Consider using computers for sensor reliability checks or calibration checks (*e.g.* smart transmitters).
- Provide adequate warning systems via flashing light, speakers, or siren for high radiation sources that can change with time.

# *Appendix 4*

# Application for construction and/or operating licenses for nuclear power plants – design aspects related to ORP

Note that regarding sections A through D, while the focus of effluent systems is often on management of dose to members of the public, there will also be aspects of technology application[1] or avoidance that affect management of doses to the worker. An example may be the shielding of a room used for storage of reactor water clean-up resin in preparation for shipping the resin as radioactive waste.

## A. Airborne effluents

- Limits on operation.
  - Airborne effluent monitoring instrumentation and set points.
  - Airborne effluent concentrations and/or release rates of noble gases, halogens, tritium and particulates.
- Gaseous waste management system.
- Means of demonstrating compliance with regulatory limits related to airborne effluents.
  - Meteorological data applicable to release point(s).

## B. Waterborne effluents

- Limits on operation.
  - Liquid effluent monitoring instrumentation and set points.
  - Liquid effluent concentrations and/or release rates of radionuclides (e.g. fission products, activation and corrosion products, and dissolved noble gases).
  - Liquid waste management system.
- Groundwater protection programme (e.g. prevention and control of leaks and spills to soils or groundwater).

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[1] Technology is added sequentially and in order of diminishing cost-benefit return where feasible.

- Means of demonstrating compliance with regulatory limits related to waterborne effluents.
    - Hydrological data applicable to release point(s).

## C. Solidified and/or dewatered effluents and dry active waste

- Limits on operation.
    - Solidified and/or dewatered effluent monitoring instrumentation and set points.
- Solid waste management system.
- Means of demonstrating compliance with regulatory limits related to solidified and/or dewatered waste classification, waste shipping and waste disposal.
- Means of demonstrating compliance with regulatory limits related to shipping and disposal of dry active waste.

## D. Total dose from effluents

- Potential dose to members of the public.
    - Methods.
    - Reporting of effluents and calculated doses.

## E. Radiation safety facilities

- Radiochemistry laboratory(s).
    - Facilities for receiving, storing, preparing, analysing and disposing of sample media.
    - Facilities for worker protection (e.g. shielding, fume hoods, sinks and drains, emergency shower/eyewash stations).
- Access control facility for entrance and exit of personnel and materials to/from the radiologically controlled area; change areas for members of staff; facilities for radiation safety staff oversight of entry and exit.
- Personnel decontamination areas.
- Portable instrument calibration facility.
- Respirator facility.
- Equipment decontamination facility.
- Machine shop for activated/contaminated components and equipment.
- Storage and issue area for contaminated tools and equipment.
- Radioactive materials storage area.

- Facility for dosimetry and bioassay (e.g. for dosimetry, facilities to support storage, issue and processing in a low-radiation field environment).
- Laundry processing facility.
- Area radiation monitoring system.
- Central facility for remote monitoring, plus in-plant capability (e.g. appropriate wiring and penetrations) for use of cameras and teledosimetry.
- Radiation safety offices.

## F. Cost-benefit analysis

Description of items in the effluent management system of reasonably demonstrated technology that can for a favourable cost-benefit ratio effect reductions in dose to workers and the public within 80 kilometres of the facility. The value used to demonstrate a favourable or unfavourable ratio shall be that established by the country in units of the country's currency per person-Sv avoided by inclusion of the technology. In absence of a value established by the country, the applicant shall use a value specified in the application and state its comparison to values used in other countries in the region or continent, as appropriate. If technology with a favourable cost-benefit ratio is not included in the facility design, the applicant should provide justification for that decision.

Description of items related to individual and collective dose (and monitoring thereof) to workers of reasonably demonstrated technology that can for a favourable cost-benefit ratio effect reductions in dose to workers. The value used to demonstrate a favourable or unfavourable cost-benefit ratio would be as described in the paragraph above.

## *Appendix 5*

# Optimisation of occupational radiological protection in the design of the new European pressurised reactor (EPR)

### Optimisation approach

In order to optimise the dose received (both in terms of collective dose and individual dose) by the workers during the operating period of the EPR, the following issues were addressed:

- Take into account feedback and best practices at the current nuclear power reactors.
- Optimise the dose received by the most exposed workers (thermal insulators, welders, mechanics etc.).
- Be able to intervene, in particular for maintenance work, during operations at power in order to improve the availability of the nuclear reactor fleet, while still complying strictly with ORP regulations.
- Achieve the best (optimal) level of ORP for all workers.

The first step concerns data collection from the best French NPPs; the EDF is the sole nuclear reactor operator, therefore the company is able to establish countrywide statistics in terms of dose (effective dose and collective dose). The plant series of 1300 MWe and 1450 MWe achieved an average collective dose of 0.69 manSv in 2006, and the level of the best performance is 0.44 manSv per reactor unit per year. This number is regarded as the first dose constraint at the beginning of the process.

As some improvements are expected in the EPR radiological protection performance, especially concerning the source term, studies are carried out to identify improvements which could be made at the project design stage, for example: accessibility improvements taking into account human factors and conventional safety, measures to isolate radioactive materials within the facility, improvements in ease of fuel handling, possibility of carrying out in-service inspections, and the use of robotics or automation. The activities which result in the highest doses of radiation are identified and are the subject to detailed studies. Taking into account these improvements, an initial level of collective dose believed achievable at a new reactor is set equal to 0.39 manSv per reactor unit per year.

After this first stage, an optimisation target is set at ~90% of the expected achievable collective dose. Therefore a value of 0.35 manSv per reactor per year is defined as the collective dose objective for the EPR.

Solutions for reducing the anticipated accrued dose are based on the lessons learnt from the operating NPPs: feedback on maintenance operations, evaluation of achievable gains, identification of the requirements (technical and cost constraints), and the feasibility of the integration of the examined solutions. Finally a decision is made by an ALARA committee (consisting of representatives from the designer and the operator). Both the source term and the work hours in areas with elevated radiation fields are optimised, especially regarding high dose workplaces.

## Methodology

The items first investigated for the plant design concern measures to avoid or to reduce the sources of radiation.

At the design stage, several technical options are considered to reduce source terms and hence dose rates, as far as reasonably possible. During maintenance work and repairs, especially in the dose relevant refuelling phase, individual exposure is primarily caused by corrosion product deposits and the unshielded exposure rate of the component to be processed. Among other factors determining the source term, special attention is given to the choice of materials.

The main options adopted aim to reduce the cobalt residual content in the primary circuit stainless steel, and to optimise (reduce to the extent reasonably feasible) the use of stellite based coatings (valves, internal reactor vessel components, control rod drive mechanisms). Whenever possible, cobalt based hard facing alloys are avoided in systems containing primary coolant or in those that are directly linked to the reactor coolant system. For example, no stellite is used for the primary circuit valves.

Cobalt impurity content of steam generator tubes is minimised as much as possible taking the state-of-the-art materials technology into consideration.

For fuel assemblies, Zircaloy is chosen instead of Inconel. As far as possible, the presence of nuclides like antimony and silver is limited (not used in alloys, cladding of control rods and secondary neutron sources). Antimony is also replaced in reactor coolant pumps.

Special attention is paid to the design of the components and piping in systems containing radioactive materials so that deposition is limited, *e.g.* corners, gaps and dead zones of flow are avoided, and a sufficient velocity in pumps, valves and piping is chosen.

Layout features such as accessibility, separation, shielding, handling and set down areas are also considered.

Since slightly increasing distance from the source does not significantly enhance the attenuation of the radiation emitted by large components such as tanks and heat exchangers, the plant is subdivided into individual compartments in which large components with high exposure rates are installed. To offer protection against radioactive flux (neutrons and high energy gamma radiation), studies have resulted in the installation of a concrete floor and of shielding at the outlets of primary circuit pipes. Steam generator bunkers and pumps have also been reinforced. All these measures will ensure that the accessible area can be posted as a "green area" (dose rate < 25 microSv/h), with a neutron dose rate of less than 2.5 microSv/h.

Radiation exposure is influenced by airborne activity levels arising from access to the Reactor Building during power operation. In order to limit internal exposure, the Reactor Building is divided into an equipment compartment (made up of the main elements of the primary circuit) and a service space where access to the unit during power operation is possible with basic protective clothing.

Separately shielded compartments are provided for small components (valves, pumps) unless they must be installed near other components. Here, too, the components are separated, depending on exposure rate, component size and processes involved. Special piping ducts are foreseen to reduce the sources of radiation and to provide more space in other compartments. Facilities for local normal operation are installed in special shielded compartments (service corridors, control stations etc.), separated from large sources of radiation exposure depending on the frequency of occupancy and exposure rate.

Non-contaminated equipment is physically separated from systems and equipment that could become contaminated. In the same way, pumps and valves are installed in separate rooms. Instrumentation and control equipment (sensors) are separated from other equipment that could become contaminated; equipment installed in a controlled zone is made easily accessible in order to reduce exposure time for maintenance and inspection staff. The work preparation is performed in low dose rate level areas.

The components are designed in order to reduce the frequency of maintenance work and the necessary effort involved per operation.

Work areas giving the most important contribution to the radiation doses have been selected as subjects of design recommendations, including the possible use of remote control and remote monitoring. Attention has been paid to potential dose reductions in the scope of in-service inspections; in particular, the number of welds to be inspected in areas with high-local dose rates is kept to a minimum. The welds are designed so as to facilitate in-service inspections.

Valves and pumps are designed to eliminate the occurrence of leaks that would necessitate repairs.

# *Appendix 6*

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# Occupational Radiological Protection Principles and Criteria for Designing New Nuclear Power Plants

Global demand for electricity continues to grow and numerous new nuclear power plants (NPPs) are being planned or constructed in NEA member countries. Most of these new NPPs will be of the third generation, and will be designed for as long as 80 years of operation. The successful design, construction and operation of these plants will depend broadly on appropriately implementing the lessons from experience accumulated to date.

This case study introduces a policy and technical framework that may be used when formulating technical assistance and guidance for senior managers of NPPs, designers, manufacturers, contractors and authorities responsible for regulating occupational radiation exposure. It is aimed in particular at assisting design and license assessments of new NPPs. Although not targeting the needs of countries introducing nuclear power for the first time, this case study can also provide valuable input on occupational radiological protection issues for the implementation of new nuclear energy programmes.

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