Radiation Protection

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Effluent Release Options from Nuclear Installations

Technical Background and Regulatory Aspects

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NUCLEAR ENERGY AGENCY
ORGANISATION FOR ECONOMIC CO-OPERATION AND DEVELOPMENT

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Pursuant to Article 1 of the Convention signed in Paris on 14th December 1960, and which came into force on 30th September 1961, the Organisation for Economic Co-operation and Development (OECD) shall promote policies designed:

- to achieve the highest sustainable economic growth and employment and a rising standard of living in Member countries, while maintaining financial stability, and thus to contribute to the development of the world economy;
- to contribute to sound economic expansion in Member as well as non-member countries in the process of economic development; and
- to contribute to the expansion of world trade on a multilateral, non-discriminatory basis in accordance with international obligations.

The original Member countries of the OECD are Austria, Belgium, Canada, Denmark, France, Germany, Greece, Iceland, Ireland, Italy, Luxembourg, the Netherlands, Norway, Portugal, Spain, Sweden, Switzerland, Turkey, the United Kingdom and the United States. The following countries became Members subsequently through accession at the dates indicated hereafter: Japan (28th April 1964), Finland (28th January 1969), Australia (7th June 1971), New Zealand (29th May 1973), Mexico (18th May 1994), the Czech Republic (21st December 1995), Hungary (7th May 1996), Poland (22nd November 1996); Korea (12th December 1996) and the Slovak Republic (14th December 2000). The Commission of the European Communities takes part in the work of the OECD (Article 13 of the OECD Convention).

NUCLEAR ENERGY AGENCY

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

The mission of the NEA is:

- to assist its Member countries in maintaining and further developing, through international co-operation, the scientific, technological and legal bases required for a safe, environmentally friendly and economical use of nuclear energy for peaceful purposes, as well as
- to provide authoritative assessments and to forge common understandings on key issues, as input to government decisions on nuclear energy policy and to broader OECD policy analyses in areas such as energy and sustainable development.

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

In these and related tasks, the NEA works in close collaboration with the International Atomic Energy Agency in Vienna, with which it has a Co-operation Agreement, as well as with other international organisations in the nuclear field.

FOREWORD

In order to help experts and decision makers become better informed about the technical implications and feasibility of various effluent release options for major operational nuclear installations, the NEA Committee on Radiation Protection and Public Health (CRPPH) created an Expert Group on the Implications of Effluent Release Options (EGRO) in March 2001. The results of this group's work will serve as decisional background information for members of the CRPPH as well as other NEA committees, and experts faced with such choices nationally. The results will also be made available as part of the CRPPH contribution to the evolution of the international system of radiation protection. The experts nominated to the group by NEA member countries are listed in Annex 1; the approved terms of reference are given in Annex 2.

The objective of this expert group was to review and discuss the implications of various release options for nuclear installations. The discussion was not aimed to be restricted to the current framework of regulation and practices. Radioactive releases have been the focus of attention in several international fora. In Europe, the OSPAR Commission, most notably, has published a long-term strategy for reducing radioactive discharges to the marine environment. The expert group did not try to interpret the *"OSPAR Strategy with Regard to Radioactive Substances"*, but it worked to provide comprehensive background information about related national and international policies and practices.

The goal of this work was also to provide basic factual information related to various options. This should assist the development of national policies and strategies on radioactive effluent releases from nuclear installations, and assist regulators in gaining an overall picture of the various factors that have an impact on the control of releases. Gaseous and liquid effluent releases were mainly considered; solid waste was addressed, to some extent, in the context of retained effluents.

The Expert Group on the Implications of Effluent Release Options (EGRO) held four meetings at NEA Headquarters in Issy-les-Moulineaux, France. Mr. Olli Vilkamo from Finland was the chairman of the group. Status reports summarising the work performed were presented to the CRPPH in March 2002 and in March 2003. At its March 2003 meeting, the CRPPH agreed to the publication of this report.

TABLE OF CONTENTS

EXECUTIVE SUMMARY

Nuclear installations operate in compliance with national and international standards and regulations for the release of radioactive effluents. The implementation of the principle "as low as reasonably achievable (ALARA)", one of the fundamental principles of radiological protection, has significantly contributed to the reduction of effluent releases to minimise their impact on the environment and the public. At the same time, international and intergovernmental agreements and declarations, as well as national policies, have increasingly focused on effluent releases from nuclear installations with the aspiration of further optimising and reducing these releases. Due to societal concerns about levels of radioactivity in the environment, management of effluent releases from nuclear installations is still high on the agenda of public discussion.

The objective of this NEA CRPPH expert group report is to provide basic factual information on different options for managing and regulating radioactive effluent releases from nuclear installations during normal operation. The outcome of this NEA work is seen as a contribution to national and international discussions in this area.

In principle, decisions on effluent release management can be based on philosophically different objectives, for example on the protection of human health, on the application of state-of-the-art techniques to industrial installations, or on the desire for a clean environment. The first approach will focus on minimising the potential health impact on members of the public individually and/or collectively. The second approach will focus on employing appropriate techniques to minimise the production and release of hazardous substances at the source. The third approach will focus on the status of the environment by monitoring concentrations of hazardous substances in environmental samples, leading to demands for limiting or reducing any additional inputs. These different approaches are by no means mutually exclusive.

In practice, effluent release management employs concepts such as "as low as reasonably achievable (ALARA)", one of the basic principles of the system of radiological protection, and the concept of “best available techniques (BAT)”, as defined for different areas of non-radioactive effluent release optimisation, for example in the European Union *Integrated Pollution Prevention and Control (IPPC) Directive of 1996*. The IPPC Directive is concerned, in essence, with minimising pollution from various industrial point sources throughout the European Union.

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

The management of effluent releases from nuclear installations can make use of these concepts in various ways. The optimisation process at a single nuclear installation or source aims to achieve individual and/or collective doses to members of the public and to workers that are ALARA. The application of BAT at a single nuclear installation or source aims at limiting radioactive effluent releases from that source. Implementing BAT at all nuclear installations and sources which may have an impact on a particular ecosystem aims to achieve a reduction of concentrations of radionuclides in the environment. A holistic approach to protection of the public, workers, and the environment may include all of these uses of ALARA and BAT, taking due account of potential accident situations.

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

In the past, the optimisation of effluent releases from nuclear plants has been driven by prospective assessments of stochastic health effects on members of the public potentially exposed to radioactive emissions. This health-driven approach to protection has resulted in the development of nuclear abatement systems which concentrate and contain gaseous and liquid emissions converting them into solid waste forms for long term storage/disposal.

For nuclear installations, the concept of "best available techniques" as a management tool for optimising effluent releases is rather new, and guidance material is therefore limited. In order to give an example of how the concept of BAT could apply within the nuclear sector, this report presents a decision-aiding strategy for effluent release optimisation based on factors indicating the application of "best available techniques". It is suggested that the broad environmental principles that guide the use of BAT could be:

- the use of low-waste technology;
- the efficient use of resources;
- the prevention and reduction of the environmental impact of emissions; and
- the use of less hazardous substances.

For each of these four environmental principles, the report offers, as an example, a set of BAT factors which should help to indicate the application of "best available techniques" in nuclear installations.

Before introducing these possible management tools, a compilation and overview of relevant international agreements and declarations, activities of international organisations, evolving national policies, and the status of effluent releases as published by the UN Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) are provided.

The outcome of this NEA work should assist the development of national approaches to effluent release management. Regarding the review of the current system of radiological protection, which includes the review of the concept of optimisation as one of the basic principles of radiological protection, it is hoped that this report will provide useful technical background for further discussions on the optimisation of effluent releases.

1. INTRODUCTION

Since the early part of the 20th century when the harmful effects of ionising radiation were first observed, the primary aim of radiological protection has always been to provide an appropriate standard of protection for the public and workers, without unduly limiting the beneficial practices giving rise to radiation exposure. Over the past few decades, many studies concerning the effects of ionising radiation have been conducted, ranging from those that examine the effects of radiation on individual cells, to epidemiological studies that examine the effects on populations exposed to different radiation sources. Using information gained from these studies to estimate the consequences of radiation exposure, together with the necessary social and economic judgements, the International Commission on Radiological Protection (ICRP) has put forward a series of recommendations as to the structure of an appropriate system for radiological protection. The most recent of these is laid down in ICRP Publication 60, 1990 Recommendations of the International Commission on Radiological Protection.

In recent years, discussion started on a possible evolution of the current system of radiological protection in order to make the system more coherent and concise. Part of this evolution is the endeavour to include explicitly the protection of the environment from ionising radiation. Until now, the system of radiological protection has focused on the protection of humans assuming implicitly that this will also appropriately protect the environment. In various international groups, work is under way to develop a rationale for radiological protection of the environment that is comprehensive and which can be implemented in an efficient manner.[1]

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1. The International Commission on Radiological Protection (ICRP) published *A Framework for Assessing the Impact of Ionising Radiation on Non-human Species (ICRP91, 2003).* The International Atomic Energy Agency (IAEA) is working towards standards in the field of environmental protection. The European Commission is supporting a scientific programme to collect, categorise and evaluate scientific knowledge in this field (FASSET).

The NEA contributed to this process of developing a policy basis for radiological protection of the environment by holding, in collaboration with ICRP, a Forum in Taormina, Italy, 12-14 February 2002. The results of this Forum, as given in a proceedings document[2] and in a policy-level summary document,[3] should help NEA member countries and the international community to better understand the issues and possible approaches.

Societal concerns about an appropriate level of radiological protection of the environment triggered discussions on the level of radioactive effluent releases from nuclear installations. Although, radioactive effluent releases from nuclear installations, in normal operation, have generally been reduced in recent years, interested stakeholders still might be concerned, in specific cases, over current levels, and exert pressure for further reductions. The discussion is partly driven by the question of how to deal with transboundary effects of radioactive releases.

As part of the activities within the *OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic,* a strategy with regard to radioactive substances sets the objective of preventing pollution of the maritime area from ionising radiation through progressive and substantial reductions of discharges, emissions and losses of radioactive substances, with the ultimate aim of concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial radioactive substances www.ospar.org.

The demand for concentrations in the environment "close to zero" poses an additional benchmark or endpoint for the protection of the environment. OSPAR has worked on issues related to this endpoint, aiming to define "close to zero" and the baseline against which the endpoint has to be judged.

Within this context, the question arises on how to organise the optimisation of effluent releases, ensuring an appropriate level of protection for man and the environment, taking account of existing societal concerns. Regarding this optimisation, there are different approaches, such as the concept of "as low as reasonably achievable (ALARA)", one of the basic principles of

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2. *Radiological Protection of the Environment: The Path Forward to a New Policy*? Workshop Proceedings Taormina, Sicily, Italy 12-14 February 2002, OECD/NEA, 2003.

3. *Radiological Protection of the Environment: Summary Report of the Issues,* OECD/NEA, 2003.

the system of radiological protection, or the “best available techniques (BAT)”, as defined in different areas of effluent release optimisation. Although actual effluent releases are well below national regulatory requirements, the ALARA and BAT optimisation approaches, which have been applied in NEA member countries for a number of years, have not so far led to concentrations of radionuclides in the environment that in all cases are regarded as “close to zero”. This report will examine and review the principles of ALARA and BAT, their implications to nuclear installations and their potential to further reduce effluent releases to achieve concentrations of radionuclides in the environment that are considered as “close to zero”.

2. SCOPE AND OBJECTIVE OF THE REPORT

The objective of this report is to provide basic factual information on different options for regulating and managing radioactive effluent releases from nuclear installations in normal operation. The report will put emphasis on the regulation and management of these effluent releases but also considers the management of effluent releases as a result of past practices, legacy and decommissioning, recognising that decommissioning and clean-up are major issues in several NEA member countries. The result should support NEA member countries in the development of national policy and strategy. The discussion will concentrate on ***optimisation*** with regard to radioactive effluent releases. *Justification of a practice,* as one of the basic principles of the system of radiological protection, is beyond the scope of this report.

The concepts of "best available techniques (BAT)" and "as low as reasonable achievable (ALARA)" are underlying approaches to the optimisation process regarding radioactive effluent releases. The report will discuss the identification of various options for routine low-level releases of radionuclides from nuclear installations, including the option of "close to zero" gaseous and liquid releases. The identification and discussion of various release options will mainly focus on managerial procedures rather than on the technical specificity of these options.

Some key implications of the options identified are also discussed, such as the radiological impact on man and the environment, transboundary impact, waste management, etc. Although gaseous and liquid radioactive effluent releases are mainly considered, solid radioactive wastes are also to some extent considered, in the context of retained effluents.

The report gives examples from effluent release options for nuclear reprocessing plants and nuclear power reactors, as these nuclear installations are, in general, the main contributors to the release of radioactive substances in normal operation. Relevant information can be found in the NEA publication *Radiological Impacts of Spent Nuclear Fuel Management Options* (OECD/NEA 2000).[4]

4. *Radiological Impacts of Spent Nuclear Fuel Management Options*, OECD/NEA, 2000.

3. SETTING THE SCENE

In order to set the scene, this chapter provides a short overview on relevant international and intergovernmental agreements and declarations, activities of international and intergovernmental organisations, and some national policies from NEA member countries.

International and intergovernmental agreements and declarations

Radioactive effluent releases are subject to several international agreements and declarations which may impose obligations on national policies and procedures. There are the *International Convention on Nuclear Safety*[5] and the *Joint Convention on the Safety of Spent Nuclear Fuel Management and on the Safety of Radioactive Waste Management*,[6] which are signed and ratified by numerous UN Member states. Member states of the European Community are legally bound by the provisions of the *Euratom treaty*,[7] *Article 37* of which deals with potential transboundary effects of radioactive discharges from nuclear installations. The *OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic*[8] imposes obligations and requirements on countries discharging to the north-east Atlantic. Several other important regional conventions exist, e.g. for the Baltic sea (HELCOM[9]), the

5. International Convention on Nuclear Safety.
6. Joint Convention on the Safety of Spent Nuclear Fuel Management and on the Safety of Radioactive Waste Management.
7. Euratom treaty.
8. OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic.
9. Convention on the Protection of the Marine Environment of the Baltic Sea Area, 1992 (entered into force on 17 January 2000). The governing body of the Convention is the Helsinki Commission – Baltic Marine Environment Protection Commission – also known as HELCOM.

Mediterranean Sea (Barcelona Convention),[10] and the river Rhine.[11] The Arctic Council employs the Arctic Monitoring and Assessment Programme (AMAP) for pollution control in the relevant areas.

In the following paragraphs, details are given on some of these international and intergovernmental agreements and declarations.

International Convention on Nuclear Safety

The Chernobyl Accident in 1986 provided clear evidence of the potential for nuclear power plants to cause radiological impacts beyond national boundaries and prompted a call for an international convention that would help to prevent such accidents by providing a mechanism for attaining a high level of nuclear safety world-wide. The Convention on Nuclear Safety was adopted in 1994 and entered into force in 1996. The nuclear safety targets are contained in the articles of the Convention and the mechanism for improving safety is through the "peer pressure" exerted upon each other by the Contracting Parties at the regular review meetings.

With regard to the controlled release of effluents from nuclear power plants, Article 15 (Radiation Protection) of the Convention requires that:

> *"Each Contracting Party shall take appropriate steps to ensure that in all operational states the radiation exposure to the workers and the public caused by a nuclear installation shall be kept as low as reasonably achievable and that no individual shall be exposed to radiation doses which exceed prescribed national dose limits"*

Nevertheless, as will be discussed later in this report, there have been active debates on the subject of discharge control at the Review Meetings of the Convention. The first Review Meeting of the Convention was held from 12-23 April 1999.

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10. Barcelona Convention: Convention for the Protection of the Marine Environment and the Coastal Region of the Mediterranean.

11. Convention on the Protection of the Rhine. The governing body of the Convention is the International Commission for the Protection of the Rhine (ICPR).

Second Review Meeting of Contracting Parties to the Convention on Nuclear Safety

The Second Review meeting of Contracting Parties to the Convention on Nuclear Safety, held from 15-26 April 2002 expressed the following statement in the final report on radioactive releases from nuclear facilities:

Some contracting parties announced that they are currently reviewing their regulatory limits for radioactive discharges, now also addressing chemical discharges, with a view of reducing them. Other contracting parties expressed the view that ALARA objectives can be achieved without reducing the regulatory limits.

Various discussions in the review meeting which concerned the existing and possible regulatory approaches were intensive. Traditional risk-based approach and ALARA requirements give still with good reason bases for a comprehensive framework of setting legal requirements. It is a question of public involvement in the process and also of the real efficiency of the regulatory work whether a new national decision on decreased regulatory release limits is felt to be beneficial for the operation of nuclear facilities. Present-day technological development allows a decrease of these limit values closer to the operational results on-site.

Joint Convention on the Safety of Spent Nuclear Fuel Management and on the Safety of Radioactive Waste Management (Joint Convention)

The Preamble of the Convention on Nuclear Safety affirms “the need to begin promptly the development of an international convention on the safety of radioactive waste management as soon as the ongoing process to develop waste management safety fundamentals has resulted in broad international agreement”. The IAEA’s Safety Fundamentals on “The Principles of Radioactive Waste Management” were published in 1995 and the Joint Convention, which has its technical basis in the Safety Fundamentals, was adopted in 1997 and entered into force in 2001. The Convention on Nuclear Safety and the Joint Convention are “sister” conventions and resemble each other in their structures and *modus operandi*.

Several Articles of the Joint Convention address issues related to discharges. The principal reference is in Article 24 (Operational Radiation Protection); part 2 requires that:

> *"Each Contracting Party shall take appropriate steps to ensure that discharges shall be limited:*
>
> *(i) to keep exposure to radiation as low as reasonably achievable, economic and social factors being taken into account; and*
>
> *(ii) so that no individual shall be exposed, in normal situations, to radiation doses which exceed national prescriptions for dose limitation which have due regard to internationally endorsed standards on radiation protection."*

In this context, "discharges" are defined as meaning

> "planned and controlled releases into the environment, as a legitimate practice, within limits authorized by the regulatory body, of liquid or gaseous radioactive materials that originate from regulated nuclear facilities during normal operation".

However, in addition, under Articles 6 and 13 on Siting, each Contracting Party is required to

> *"consult Contracting Parties in the vicinity of such a facility, insofar as they are likely to be affected by that facility, and provide them, upon their request, with general data relating to the facility to enable them to evaluate the likely safety impact of the facility upon their territory"*

and to

> *"take appropriate steps to ensure that such facilities shall not have unacceptable effects on other Contracting Parties…."*

The first Review Meeting of the operation of the Joint Convention will be held in November 2003.

Euratom treaty

At the time of signature of the Euratom Treaty in 1957, its main objective was *"to contribute to the raising of the standard of living in the Member States and to the development of relations with the other countries by creating the* *conditions necessary for the speedy establishment and growth of nuclear industries.”*. This promotional role was to be achieved by conferring to the Community far reaching competence to ensure the availability of nuclear materials for civil purposes (ownership of fissile material, safeguards), access to research and technical information, and investment funds. In addition, the development of nuclear industry should be conditioned by the establishment of “uniform safety standards to protect the health of workers and the general public”, the application of which shall be ensured by the Community.

While this promotional role no longer has the same importance as in the 1950s and 1960s, with some Member States using nuclear energy and some in opposition to it, the relevance of Chapter III, Health and Safety, of the Treaty is undiminished. Key features are the uniformity of the standards, which allows the nuclear industry to operate in a stable environment, and the extensive provisions ensuring acceptable levels of radioactivity in the environment (“air, water and soil”), which allow non-nuclear Member States to be well informed on the impact of nuclear industry.

Article 2 (b) of the EURATOM Treaty provides for establishment within the Community of *“…uniform safety standards to protect the health of workers and of the general public”* and for the Community to “*…ensure that they [the standards] are applied”.*

Chapter III of the Treaty, consisting of Articles 30-39, deals with “Health and Safety” and amplifies specific responsibilities: Articles 30-33 cover the Basic Standards and Articles 34-38 cover environmental radioactivity.

The most recent revision of the Basic Safety Standards Directive was adopted by the Council in May 1996 (Council Directive 96/29/EURATOM),[12] due for implementation in the Member States not later than May 2000.

Article 37 Euratom

For EU Member States, one mechanism for addressing possible transboundary effects of radioactive discharges is provided by Article 37 of the Euratom Treaty. The Treaty provisions, including Article 37, legally bind

12. Euratom (1996), Council Directive 96/29/Euratom of 13 May laying down basic safety standards for the health protection of the general public and workers against the dangers of ionising radiation, Official Journal of the European Communities L-159 of 29/06/1996, Luxembourg.

Member States of the European Union. Article 37 of the Treaty requires each Member State to

> *"…provide the Commission with such general data relating to any plan for the disposal of radioactive waste in whatever form as will make it possible to determine whether the implementation of such plan is liable to result in the radioactive contamination of the water, soil or airspace of another Member State.*
>
> *The Commission shall deliver its opinion within six months, after consulting the group of experts referred to in Article 31."*

The purpose of the Article 37 procedures is to allow the Commission to give an opinion on whether there is an impact, significant from the point of view of health, on another Member state. Thus the general data allows the assessment of population exposure to reference group(s) in the nearest Member States.

Commission Recommendation 99/829/Euratom[13] issues guidance on the application of Article 37 by detailing the types of operation to be covered, by defining more precisely the meaning of "general data" and by specifying the time limits by which such data should be submitted.

The Recommendation also calls for the submission, every two years, of a statement of the radioactive waste discharges from nuclear reactors and reprocessing plants.

OSPAR Convention for the Protection of the Marine Environment of the North-East Atlantic

In 1998, the OSPAR Commission introduced a strategy with regard to radioactive substances. The OSPAR Strategy with regard to Radioactive Substances, including waste, sets the objective of preventing pollution of the maritime area from ionising radiation through progressive and substantial reductions of discharges, emissions and losses of radioactive substances, with the ultimate aim of concentrations in the environment near background values for naturally occurring radioactive substances and close to zero for artificial

13. Euratom (1999), Commission Recommendation 99/829/Euratom of 6 December 1999 on the application of Article 37 of the Euratom Treaty, Official Journal of the European Communities L-324 of 16/12/1999, Luxembourg.

radioactive substances. In achieving this objective, the following issues should, inter alia, be taken into account:

- legitimate uses of the sea;
- technical feasibility;
- radiological impacts on man and biota.

As its timeframe, the Strategy further declares that by the year 2020 the Commission will ensure that discharges, emissions and losses of radioactive substances are reduced to levels where the additional concentrations in the marine environment above historic levels, resulting from such discharges, emissions and losses, are close to zero.

The Strategy sets out a definition of radioactive substances, and provides that OSPAR will identify, assess and prioritise radioactive substances and/or human activities which give rise to concern about the impact of discharges, emissions or losses of radioactive substances. Effective action is to be taken when there are reasonable grounds for concern that radioactive substances introduced into the marine environment, or which reach or could reach the marine environment, may bring about hazards to human health, harm living resources and marine ecosystems, damage amenities or interfere with other legitimate uses of the sea, even when there is no conclusive evidence of a causal relationship between inputs and effects.

Within the OSPAR framework, a Radioactive Substances Committee (RSC) is responsible for the follow-up of the OSPAR strategy and for tracking the achievements made with the timely implementation of the strategy in OSPAR signatory states. The countries have to submit their national strategies on how to implement the OSPAR strategy. In addition, each country has the obligation to report every four years on progress with applying “best available techniques” in nuclear installations.

The Radioactive Substances Committee (RSC) is, inter alia, challenged to develop and periodically review environmental quality criteria for the protection of the marine environment from adverse effects of radioactive substances and apply these and other relevant criteria to identify and prioritise radioactive substances and/or human activities which give rise for concern about their radiological impact.

Sintra statement

During the ministerial meeting of OSPAR in Sintra, Portugal, in 1998, the ministers and the member of the European Commission emphasised

> "…our commitment to take all possible steps to achieve our overall objective for the protection of the marine environment of the North East Atlantic of preventing and eliminating pollution, protecting human health and ensuring sound and healthy marine ecosystems, and commit ourselves to pursuing this goal through the following actions to produce a sustainable approach to the marine environment of the OSPAR maritime area and thus protect this inheritance for the new millennium."
>
> In addition, the ministers re-emphasised
>
> "…the clear commitments to the application of the precautionary principle and the polluter-pays principle and to the identification of best available techniques (BAT) and best environmental practice (BEP), including, where appropriate, clean technology."

This "Sintra statement" includes a part on radioactive substances, emphasising the willingness of the ministers to ensure the implementation of the above mentioned OSPAR Strategy with regard to Radioactive Substances.

The Rio de Janeiro Conference and the precautionary principle

An international declaration on the precautionary principle was made during the United Nations Conference on Environment and Development (UNCED) in Rio de Janeiro, Brazil, 1992 and became part of Agenda 21. The Rio Declaration on Environment and Development states in Principle 15 – the Precautionary Approach

> "In order to protect the environment, the precautionary approach shall be widely applied by States according to their capabilities. Where there are threats of serious or irreversible damage, lack of full scientific certainty shall not be used as a reason for postponing cost-effective measures to prevent environmental degradation."

In the framework of Agenda 21, the precautionary principle is to be applied in cases of potential irreversible impacts on the environment with relative high consequences (implying that these consequences are unacceptable).

Governmental action should be taken without availability of complete scientific evidence. The precautionary principle could result, depending on the area where it is applied, in quite different types of environmental policies or regulation.

Activities of international and intergovernmental organisations

Various international organisations, such as the International Atomic Energy Agency (IAEA), the United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR), and the European Commission (EC) have programmes regarding releases of radioactive substances from nuclear installations.

International Atomic Energy Agency (IAEA)

The IAEA issues safety standards covering nuclear, radiation, transport and waste safety. They are developed through a consensual process involving the regulatory authorities of the IAEA's Member States and so, while they are not legally binding, except in the IAEA's own activities in the Member States, they have the authority given by this formal approval process. In relation to discharge control, the principal requirements are contained in the International Basic Safety Standards for Protection against Ionizing Radiation and for the Safety of Radiation Sources (BSS) (IAEA Safety Series 115). The BSS translates the basic radiation protection recommendations of the International Commission on Radiation Protection (ICRP) into regulatory form. The essential requirement is that:

> "Registrants and licensees, shall ensure that radioactive substances from authorised practices and sources not be discharged to the environment unless:
>
> - the discharge is within the discharge limits authorised by the Regulatory Authority;
> - the discharges are controlled;
> - the public exposures committed by the discharges are limited as specified in Schedule II [the dose limits];
> - the control of the discharges is optimised in accordance with the Principal Requirements of the Standards."

Detailed guidance on setting discharge authorisations is contained in a Safety Guide "Regulatory Control of Radioactive Discharges to the Environment" (IAEA Safety Standards Series No.WS-G-2.3, 2000). This Safety Guide outlines the responsibilities of the Regulatory Body and of the organisation intending to discharge radioactive material, sets out the steps to be followed in setting a discharge authorisation for a new practice, gives advice on actions to be taken in cases of non-compliance and on the procedures to be followed for existing discharge practices.

The IAEA has provided further guidance on "Generic Models for Use in Assessing the Impact of Discharges of Radioactive Substances to the Environment" in Safety Report No.19, 2001.

The IAEA is currently updating its guidance on source and environmental monitoring and will issue a Safety Guide with supporting Safety Reports on the subject.

To supplement its existing data bases on the past disposal of solid radioactive waste in the oceans, the IAEA has recently established a data base containing information on discharges of liquid and gaseous radioactive substances to the environment. Information for this data base (acronym DIRATA) is being collected with the help of established contact points in IAEA Member States and with the involvement of the EC which has a similar data base for its own Member States.

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

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) was established by the General Assembly of the United Nations in 1955. Its mandate in the United Nations system is to assess and report levels and effects of exposure to ionising radiation. Governments and organisations throughout the world rely on the Committee's estimates as the scientific basis for evaluating radiation risk, establishing radiological protection and safety standards, and regulating radiation sources.

The Committee produces detailed reports which review exposures from natural radiation sources, from nuclear power production and nuclear tests, exposures from medical radiation diagnosis and treatment, and from occupational exposure to radiation. The 1996 UNSCEAR Report[14] included a Scientific Annex on Effects of Radiation on the Environment, which contained a review of information on radiation exposures to plants and animals in their natural habitats from the various sources of radiation, and their responses to acute and chronic irradiation (as individuals and populations). As an example, it was concluded that:

- "…chronic dose rates less than 400 microGy/h (10 mGy/d) would have effects, although slight, in sensitive plants but would be unlikely to have significant deleterious effects in the wider range of plants present in natural plant communities"; and
- "For the most sensitive animal species, mammals, there is little indication that dose rates of 400 microGy/h to the most exposed individual would seriously affect mortality in the population. For dose rates up to an order of magnitude less (40-100 microGy/h), the same statement could be made with respect to reproductive effects".

UNSCEAR has established a related work programme which will undertake a pathways analysis, identify appropriate biological endpoints for use in environmental assessments and appropriate methods for assessments of dose to biota. It will also include a review of evidence of impacts at specific sites. A report of this work is likely to be published around 2005-2006.

European Commission

A *Working Party on harmonisation of discharge data (Article 37)* has recently proposed legislation on standardised information on radionuclides released to the environment from nuclear power reactors and reprocessing plants during normal operation. One of the aims is to achieve comparable measurement results on a Community scale and to ensure that minimum standards for the methods of analysing radioactive releases are applied in the laboratories across the Community.

The reported information on radioactive releases will include, *inter alia*, annual releases for listed radionuclides and the achieved detection limits for a number of key radionuclides. A new release database will allow electronic data

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14. Sources and Effects of Ionising Radiation, United Nations Scientific Committee on the Effects of Atomic Radiation, UNSCEAR 1996 Report to the General Assembly, with Scientific Annex.

collection from the Member States and will provide data transmission to DIRATA, an IAEA database, in the framework of UNEP-GPA(RAD).

A framework for radiological protection of non-human species is being developed under the Euratom 5th Framework Programme. The project is known as FASSET (Framework for ASSessment of Environmental impacT). The 15 organisations supporting the project recognise that the statement made in ICRP 60, to the effect that radiological protection of human beings also provides protection of non-human species, cannot stand in unsupported form indefinitely. The outcome of the FASSET project is expected in October 2003. A bid for a further project, which would run for another 3 years to develop and extend the FASSET work, is being made under the Euratom 6th Framework Programme. The eventual outcome is expected to deliver a systematic basis for regulation to provide protection of non-human species.

The European Commission has recently performed a programme called *Realistic assessment of radiation doses to the members of the public due to the operation of nuclear installations under normal conditions (RAIN)*. The main objective of this project was to assist member states to fulfil their requirements to perform a realistic dose assessment, as stipulated in Council Directive 96/29/Euratom, and more in particular in Article 45 thereof. The results of RAIN are published in number 129 of the EC Radiation Protection series.

In order to contribute to the development of the European Commission policy relating to the principles for the protection of the natural environment from ionising radiation, the EC commissioned and funded the MARINA II Study. The study, published in 2003, provides an overview on the discharges to the marine environment, concentrations in the marine environment, doses to members of critical groups, and an assessment of the impact on biota. The results are used as a scientific contribution to the work of the OSPAR Radioactive Substances Committee in implementing the OSPAR Strategy with regard to radioactive substances.

WHO/FAO Radioactivity levels in foodstuff

One issue of concern in the regulation of radioactive discharges is the uptake of radionuclides into terrestrial and marine foodstuffs. The application at a national level of the ICRP principles of optimisation and dose limitation will ensure that radiation doses incurred as a result of foodstuff consumption are generally low. Nevertheless, elevated concentrations of radionuclides attributable to discharges from artificial sources may still be detectable in certain foodstuffs.

Currently the only international agreements for the control of radioactivity in foodstuffs applies in post-accident situations. International discussions on the radiological control of foodstuffs are ongoing. Following the Chernobyl accident, the WHO/FAO Codex Alimentarius Commission developed guidelines on radionuclide levels in food in the year following a nuclear accident, below which trade restrictions should not be imposed based on radiological considerations. The European Commission has also issued a directive in this area following broadly the Codex approach. However, agreement on more general guidelines for radiological concentrations in foodstuff remain under discussion.

National Approaches

In recent years, several countries within the OECD have evaluated their national strategies and regulations regarding radioactive effluent releases from nuclear installations. The following paragraphs will describe some national approaches based on the information received from EGRO members in 2002.

Belgium

In ***Belgium*** the "Agence Fédérale de Contrôle Nucléaire" (AFCN) was established on 01/09/2001, as a result of the implementation of the law of 15/04/1994 relating to the protection of the population and the environment against risks resulting from ionising radiation and relative to the "Agence Fédérale de Contrôle Nucléaire". The Law gives the Agency a number of assignments relating to *regulations,* (drafting of regulations of various kinds and management of many procedures, especially authorisation procedures), and relating to the *monitoring* of practices and activities and supervision of the territory (article 70 – monitoring of the radioactivity in the territory and the doses received by the population, and article 71 – supervision of the population as a whole).

The operational introduction of the AFCN was accompanied by the publication of a new *General Regulation for Protection of the Population, Workers and the Environment against the risk of ionising radiation* (Royal Decree of 20.07.2001). It includes in particular provisions limiting the exposure of the public, now reduced to 1 mSv/y. Nevertheless, any exposure must be maintained at as low a level as is reasonably possible (ALARA), taking account of economic and social factors. This new General Regulation introduce also the notion of "*contrainte de dose*" for the nuclear installations, which is fixed by the AFCN, after consultation with the operator, and represents a fraction of the maximum effective dose for the general public. The new general regulation also covers the transposition of the more recent European Directives.

A Revision of maximum discharges has currently begun at the Agency by an in-depth examination of the existing situation for all Class 1 establishments. The necessity of reducing or not the maximum discharges while taking account of the new obligation to comply with a maximum population dose of 1 mSv/y will be assessed.

In fact, Article 81.2 of the General Regulation provides that: *"Within a maximum period of one year from the date of publication of the present decree in the "Moniteur Belge"* (Royal Decree of 20 July 2001; published in the Moniteur of 30 August 2001), *the operator of a Class 1 or Class 2 establishment is required to submit a file to the authorities issuing the authorisation (AFCN) in which a modification is proposed in the maximum discharges allowed to his establishment in order to bring these into line with the maximum dose for the public defined in Article 20 of the present decree or in which he justifies the maintenance of these maximum discharges. The opinion of an approved body will be attached to this file."* The files in question have been returned to the Agency and are currently being examined.

In order to optimise the production of solid waste, while respecting the authorised discharge limits, nuclear power plant operators have adopted the recommendations for the exploitation of effluents. This policy of implementation of the BAT is illustrated by the evolution of the quantity of liquid and solid waste generated by the nuclear power stations: although total production of electricity has remained more or less constant since 1985-6 and has even increased slightly since 1997, the quantity of radioactivity in liquid effluents is still decreasing and this finding is increasingly true when one looks at the volume of solid waste generated per TWh produced.

Discharges of liquid effluents have a dosimetric impact of about 10 μSv per year for the public, according to conservative estimates. This impact is therefore negligible as a number of orders of magnitude below the doses may involve a health risk to the population.

Upon the constitution of the present government, an agreement was made on 28 July 1999 between the various political parties; this agreement includes a section on sustainable development, more particularly in the power and electricity sector, and has been adopted recently by the Belgian Parliament. Consequently, the oldest PWR units will be dismantled around the year 2015.

Finland

In ***Finland*** the Decision of the Council of State (General Requirements on Nuclear Power Plants' Safety, Decision No 395, 1991) gives following requirements on radioactive release restriction: "Radiation exposure arising from the operation of a nuclear power plant shall be kept as low as reasonably achievable (ALARA). A nuclear power plant and its operation shall also be designed so that the limits presented in this decision are not exceeded. The limit for the dose commitment of the individual of the population, arising from normal operation of a nuclear power plant in any period of one year, is 0.1 mSv. Based on this limit, release limits for radioactive materials during the normal operation of a nuclear power plant are to be defined." Additionally another paragraph states: "For further safety enhancement, actions shall be taken which can be regarded as justified considering operating experience and the results of safety research as well as the advancement of science and technology."

Radiation and Nuclear Safety Authority (STUK) issues the more specific safety requirements in YVL Guides. Guide YVL 7.1 defines a set of further release restrictions based on 'Reference Release Rate' which is a calculated average release rate which corresponds to the authorised annual Release Limit. Reporting threshold to STUK is 5 times Reference Release Rate (averaged over a week at most). Threshold requiring Corrective Action is 3 times Reference Release Rate (averaged over a month at most). Corresponding release thresholds and limits are to be included in the Technical Specifications of each nuclear power plant unit. There shall also be a clear restriction on the operation of a nuclear power plant if it became evident that the Release Limits determined in the Technical Specifications would be exceeded.

There are several other YVL Guides indicating e.g. requirements for the methods of dose calculation, measurement of the releases, environmental surveillance and periodic reporting of operational release and environmental data.

There is also a permanent safety goal for STUK regulatory work in the annual agreement between STUK and the Ministry of Social Affairs and Health: radioactive discharges from nuclear power plants into the environment are small and the incurred radiation doses to the public shall be below 5% of the limit prescribed in the Decision of Council of State (395/91).

Radioactive discharge limiting ALARA measures have been implemented at Finnish nuclear power plants since the start of the operation (in late 70s or early 80s). The theoretically calculated annual individual doses are in the order of 0.1% of the limit value (less than 0.1 μSv/year). The operators of nuclear power plants have formally committed to specific environmental safety objectives by company level policy-decisions. The new environmental goals are developed at the same time when environmental certification processes on-site at the NPPs have been finalised. At Loviisa NPP a caesium separation technique from liquid effluent tanks has been operational for several years which also very efficiently decreased the activity of releases to the marine environment. At Olkiluoto NPP the activity of liquid effluents is recently decreased e.g. by new equipment for filtering liquid waste (centrifugal separation) and more efficient evaporation in addition to the reuse of pool water during reactor refuelling.

TVO nuclear company got a positive decision-in-principle for a new nuclear power plant project from the Council of the State which was enforced by the Finnish Parliament in May 2002. This legal process was pre-ceded also by the Environmental Impact Assessment process during 1998-2000 where both present NPP sites were comprehensively evaluated as alternative candidate sites for a possible new reactor of 1 000-1 500 MWe electric output.

Finland has signed the OSPAR Convention. Radioactive releases from Finnish nuclear power plants are not directed to the North Atlantic marine area, which is covered by the OSPAR Convention, but to the Baltic Sea.

France

In ***France***, Decree 95-540 of 4 May 1995, and an Order dated 26 November 1999, set out technical directions concerning the discharge limits and method of sampling from discharges released by "Basic Nuclear Installations (BNI)"; the creation of these installations and their discharges both being subject to specific authorisation.

The order states, in Art. 8 for atmospheric discharges and in Art. 15 for liquid discharges, that "the equipment has to be designed, operated and maintained so as to limit the emissions of effluents. These emissions are to be, as much as possible, collected at their source, monitored and, if necessary, treated in such a way that corresponding discharges are kept as low as reasonably possible. In any event, discharge limits will be set on the basis of the use of the best available technologies at an economically acceptable cost, and taking account of specific environmental characteristics of the site." The implementation of BAT in terms of the OSPAR Convention is thus clearly transcribed in French national legislation.

The policy of the Nuclear Safety Authority on Release Licences for BNIs: In accordance with the OSPAR statement made in Sintra, in 1998, the

Nuclear Safety Authority (DSIN,[15] the French Nuclear Installation Safety Directorate) intends to reduce the release limit values to bring them closer to real release values during routine operation. It is of particular importance that authorised effluent release limit values be as low as is technically and economically feasible, thus forcing operators to lower releases by using the best available technologies at an acceptable cost, while complying with the quality of the natural environment.

The rationale for setting discharge limits relies upon both best available technology and dose constraints. The operator has to demonstrate that every reasonable effort is made at each step of the process, from the effluent generation to the ultimate treatment, in order to keep the impact to the critical group or groups as low as reasonably possible, and the impact resulting from the complete use of the authorisation must lead to an impact much lower than the regulatory limit, so that its addition to the impact of other sources does not lead to an impact greater than the regulatory limit. This process is consistent with the dose constraint principle.

National regulation (1995 Decree, 1999 Order) requires that the environment should be protected against the effects of discharges and that the environmental site specific characteristics should be taken into account in the limitation of discharges.

Germany

In ***Germany*** the New Nuclear Energy Act (Atomgesetz – AtG) entered into force on 27 April 2002. This "Act on the structured phase-out of the utilisation of nuclear energy for the commercial generation of electricity" makes fundamental amendments to the 1959 Atomic Energy Act: Instead of aiming at promoting nuclear energy, the purpose of the act now is to phase out its use in a structured manner. Consequently it prohibits the construction of new commercial nuclear power plants in Germany and provides a framework for the operation of the existing plants before these are shut down.

For existing nuclear installations the Nuclear Energy Act and the revised Radiation Protection Ordinance (Strahlenschutzverordnung – StrlSchV) of 1 August 2001 continue to provide the framework for standards, guidelines and

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15. The former DSIN is now referred to as the Direction Générale de la Sûreté Nucléaire et de la Radioprotection (DGSNR).

objectives in the field of production of nuclear energy and application of nuclear techniques. Fundamentals of the legislation are:

- avoidance of unnecessary radiation exposure to public;
- avoidance of unnecessary contamination of humans and environment; and
- minimisation of radiation exposure and contamination taking into account the state of scientific and technological advancement.

In accordance with the EU Basic Safety Standards Directive (96/29 Euratom) the revised Radiation Protection Ordinance sets a dose limit of 1 mSv for members of the general public. Additional limits for doses resulting from radioactive discharges and emissions from nuclear installations are specified for aerial and liquid releases each:

1	individual effective dose	0.3 mSv/y
2	partial body dose for gonads, uterus, red bone marrow	0.3 mSv/y
3	partial body dose of all organs and tissues unless under 2 and 4	0.9 mSv/y
4	partial body dose of bone surface and skin	1.8 mSv/y

Doses have to be calculated for a reference person at defined points of impact, taking into account relevant exposure pathways and predefined living habits. Emissions and discharges from other nuclear installations must be taken into account.

For nuclear installations in Germany, the state of scientific and technological advancement, taking into account the BAT, is defined in technical guidelines issued by the Nuclear Safety Standards Commission (Kerntechnischer Ausschuß – KTA). The safety standard series on “Activity Control and Activity Management” contains requirements for technical specifications and detailed information on techniques to be used. Further guidelines give detailed instructions on discharge monitoring. Additional regulations are issued by the German Institute for Standardisation (Deutsches Institut für Normung – DIN) containing further requirements affecting the treatment of radioactive effluents. The safety standards issued by the KTA and the DIN are reviewed on a regular basis every five years.

All licensing and supervising activities concerning the construction and operation of nuclear facilities are carried out by the regulatory authority of the state (Land), in which the facility is located. This applies also to the authorisation of radioactive discharges to the environment. The authorities in the federal states are themselves supervised by the Federal Ministry for the Environment to ensure uniform criteria of authorisation and supervision throughout the country.

Japan

In ***Japan***, the administrative organisations of the central government underwent extensive reorganisation and realignment in January 2001. Under the new administrative structure, the Ministry of Economy, Trade and Industry (METI) is the presiding ministry in charge of safety regulation for all facilities and activities concerning utilisation of nuclear energy, and the Nuclear and Industrial Safety Agency (NISA) has been established as a special organisation under the METI, dedicated to the administration of safety regulations.

The national standards of radiation protection for a nuclear installation are provided in the Law for the Regulation of Nuclear Source Material, Nuclear Fuel Material and Reactors and the Electricity Utilities Industry Law, etc. and related government ordinances, ministerial orders and notifications based on these laws, and guidelines. The recommendations of the ICRP are given due consideration and are incorporated into national legislation and regulations. The ICRP 1990 Recommendation (Publication 60) was incorporated into them on radiation protection in April 2001, after revision of related ministerial orders and notifications.

Ministerial orders, the Rules for Commercial Power Reactors and Rules for Reprocessing Plants, etc. established on the basis of the Reactor Regulation Law, prescribe release or disposal of radioactive waste and monitoring of released radioactive materials, etc. The Notification for Dose Limits was enacted on the basis of the orders. For the public, the dose limits are 1 mSv/y of effective dose, and 15 and 50 mSv/y of equivalent dose for eye lens and skin respectively in the notification. The concentration limits of radioactive materials outside peripheral monitoring area are also prescribed.

Operators have paid much effort not only to comply with the allowable dose limits but also to reduce doses in line with ALARA concept. In examining the application of an establishment license for a nuclear installation, it is confirmed that the application conforms to the Examination Guides established by the Nuclear Safety Commission of Japan (NSC) as well as the legislation and technical standards. The Guide for Dose Objective in the Site Vicinity, one of these Examination Guides, gives numerical values in order to reduce dose for the public as low as reasonably achievable (ALARA). In the guide, the NSC has prescribed the numerical value of 0.05 mSv, one twentieth of the dose limit to the public. The operator establishes an annual numerical discharge control guide, which corresponds to the numerical value at the site vicinity, and makes efforts to keep the discharges of radioactive effluents below the numerical discharge control value. The NISA acknowledges the numerical discharge control value and receives report on it from the operator. Consequently, the exposure dose for the public due to radioactive effluent release has been successfully reduced to the level less than 1 μSv/y.

The NSC indicates also the fundamentals of the monitoring plan and its implementation, and the evaluation of radiation dose in the Guide on Environmental Radiation Monitoring. According to the guide, the operator conducts radiation monitoring at the site vicinity during normal operation, assesses the impact upon the environment of the release, and reports the results in improving discharge control and better manage the facility. Local governments also monitor radiation level independently at the site vicinity to protect public health and safety.

Spain

The Spanish regulation of limits, surveillance and control of radioactive effluents is stated in the national Regulation on Sanitary Protection against Ionising Radiation (latest edition in 2001). This rule specifically stipulates that facilities generating radioactive wastes must be provided with adequate treatment and removal systems in order to ensure that doses due to releases are lower than the limits established in the administrative licences and that they are kept at the lowest possible value.

Two main revisions of nuclear power plants discharge limits have been accomplished in recent years in Spain.

First, a deep revision updating the radiological criteria and establishing a homogeneous system for all the plants was completed in 1997. The main criteria considered in this revision process were:

- To formulate the discharge limits in terms of annual doses, applying the same dose limit to all facilities.
- To set up a total dose limit of 0.1 mSv/y. It was considered that this value represented a proper percentage of a Dose Constraint previously defined by the CSN for the fuel cycle facilities as a

whole (0.3 mSv/y), and comply with the dose limit for the public (1 mSv/y).

- To apply the annual dose limits on a monthly basis, considering 12 consecutive months rather than natural years.
- To split the total dose limit between liquid and gaseous effluents, taking into account specific treatment systems design features and site characteristics.
- To estimate site-specific release-to-dose coefficients for each nuclide liberated, in order to facilitate the control of discharges.

After the 1996 BSS Euratom Directive transposition came into force, the limitations have been up dated. A deep review of the off site dose calculations has been accomplished, modifying not only the dose coefficients, but also different factors such as the food ingestion rates, after a comprehensive study of the national values. The new limitations have come into force in January 2002.

Furthermore, the CSN established in the early 1990s so called “Reference Levels” for liquid and gaseous effluents, set up in terms of activity for groups of nuclides, that indicate the optimal operation of the reactor in terms of radioactive wastes generation and discharges into the environment. Even though values were well below the limitations, the operator is asked to justify any ever-increasing tendency and to restore the original values if feasible. By making the operators to apply the best available technologies and to improve the operation procedures releases are minimised, maintaining the quality of the natural environment.

On the other hand, licensees have to demonstrate during operation that every reasonable effort is made, from the generation of wastes to the operation proceedings of the effluent treatment systems, to reduce releases and to keep the radiological impact as low as is technically and economically feasible. They are required to develop an improvement program to analyse the safety conditions of the plant taking into account the applicability of new regulation, the progress in technology (BAT), and the operational experience. In recent years the licensees have also been required to perform a periodic safety review programme on a ten years basis, intended to:

- analyse the global behaviour of the plant over a long period;
- guarantee that lessons learned from the analysis of the operational experience have been properly implemented;

- evaluate the applicability to the facility of relevant changes in the new generation plants.

Therefore, the Spanish regulatory system in this field sets up a framework for the effective application of a clearly stated policy under which the equivalent of BAT is required, which adopts principles to ensure the application of the precautionary principle and the prevention of pollution.

Sweden

In ***Sweden***, the regulations (SSI FS 2000:12, issued by the Swedish Radiation Protection Authority) concerning protection of human health and the environment in the event of radioactive releases from certain nuclear facilities entered into force 1 January 2002. The regulations are based on the Radiation Protection Act, including protection of the environment, from 1988, the EU Directive 96/29/Euratom, the new Environmental Act (1998), the decision of the Swedish Parliament for a safe radiation environment as one of 15 Swedish environmental quality objectives, and the OSPAR convention with its strategy from 1998. In addition, the preparation of the regulation took account of 20 years of reactor operation, increased knowledge in radioecology, release perspectives based on UNSCEAR data, and the fact that Sweden is planning to phase out nuclear energy although without fixed time frame. The regulations include the protection of human health and the environment from releases of radioactive substances from nuclear power reactors, research reactors, fuel fabrication, storage and handling of spent nuclear fuel, and storage, treatment or final disposal of nuclear waste before closure.

The limitation of releases of radioactive substances from nuclear installations shall be based on optimisation of radiation protection (ALARA) and the use of best available techniques (BAT). The best available techniques are defined as the most effective measures available to limit releases of radioactive substances and the harmful effects of the releases on human health and the environment which does not entail unreasonable costs.

BAT shall be applied to all sources with special emphasis on nuclear power reactors. The present level of releases from a nuclear power reactor is called the reference value, whereas the target value is defined as the level to which releases, by applying BAT, can be reduced in a specified timeframe.

The effective dose to an individual, adults and children, due to the annual discharges from all installations in an area shall be below 0.1 mSv. If the estimated dose exceeds 0.01 mSv/y, realistic doses have to be calculated for individuals in the most affected area. The regulation stipulates requirements on the monitoring of releases, environmental monitoring, quality assurance, action plans regarding fuel failures and documentation and reporting.

For the implementation of this Swedish regulation, reference and target values had to be established, model calculations revised, critical groups newly defined and measurements of ^{14}C and ^{3}H to the atmosphere established.

United Kingdom

In the ***United Kingdom***, relevant authorities have published a new UK strategy for radioactive discharges, 2001-2020, which is intended to implement the requirements of the OSPAR Radioactive Substances Strategy agreed at the 1998 OSPAR Ministerial meeting at Sintra in Portugal. The UK has also published for consultation draft statutory guidance to regulators in England and Wales on the Regulation of Radioactive Discharges into the Environment from Nuclear Sites. The new UK strategy and statutory guidance are still to be based on the internationally agreed dose limit of 1 mSv per year for members of the public and in addition there is still a dose constraint of 300 µSv for a single source and 500 µSv for a site. The scope of the UK strategy encompasses radioactive discharges from nuclear fuel cycle facilities, nuclear power generation, research, defence and other activities. Projected discharge profiles are set out for each industry sector. Some of the main principles in the draft guidance are that there should be "progressive reductions" in levels of discharges and limits and that discharge limits are chosen to closely reflect actual levels of discharges, without large amounts of "headroom". In order to minimise discharges, the operators of nuclear installations are required to apply "Best Practicable Means" which is a UK specific expression of optimisation similar to "best available techniques (BAT)". The OSPAR strategy from 1998 led to a change in the discharge policy in the UK. The new UK strategy includes the objective to reduce radioactive effluent releases so far that by 2020 no member of the public will receive more than 20 µSv from discharges made after that date. This dose corresponds to an additional risk of approximately one in a million (10^{-6}) per annum. Public doses are assessed based on the habits of a critical group, but taking into account reasonably foreseeable habits which might arise in the future. The UK regulatory authorities are in the process of publishing a document setting out principles for the assessment of public radiation doses resulting from discharges of radioactive waste to the environment.

The new UK strategy for radioactive discharges was prepared in a process involving relevant regulatory authorities as well as the industry.

The draft statutory guidance to regulators in England and Wales states that, when considering applications for discharge authorisations, the regulators should take into account the European Community Food Intervention Levels (CFILs) so that limits on routine radioactive discharges should not, in general, be set at a level where CFILs may be exceeded.

United States

In 1991, the ***United States*** Nuclear Regulatory Commission (NRC), under the Code of Federal Regulations (CFR) established revised requirements to its standards for protection again radiation (56 FR 23360-23474). Although the 1990 revision of ICRP's Publication 60 had been issued the year before, and was available for incorporation into the U.S. regulations, the NRC, "…did not believe that additional reductions on the dose limits [were] urgently required by the latest risk estimates," as presented by ICRP Publication 60. In its statements of consideration for its revisions to 10 CFR Part 20, NRC stated that "due to the practice of maintaining radiation exposures ALARA ("as low as reasonably achievable"), the average radiation dose to occupationally exposed individuals [was] well below the limits in either the previous or amended 10 CFR Part 20 and also below the limits recommended by the ICRP." NRC stated that "until the final ICRP recommendations are published, and the need for further revisions in NRC regulations established, the Commission believes it would be advisable to proceed with the promulgation of the proposed dose limits [of 5 mSv per year], rather than deferring the dose reductions that are already associated with [its] amendments to Part 20."

As a result of the application of the ALARA philosophy to effluent release standards in Appendix I to 10 CFR Part 50 for nuclear power reactors and the U.S. Environmental Protection Agency's (EPA's) 40 CFR Part 190 for the uranium fuel cycle, dose from radioactive effluents from the fuel cycle were already much less that the 1 mSv per year standard in the final rule. The 1 mSv per year remains as the level recommended by the ICRP in 1985 as the principle dose limit for members of the general public. More recently, in 1996, 10 CFR 20.1101 required an additional ALARA value for air emissions from licensed facilities which requires that the individual member of the public likely to receive the highest dose will not receive in excess of 0.1 mSv per year from air emission. Failure to meet this requirement requires the licensee to submit a written report to the regulatory authority (NRC or the Agreement State). This change in regulation eliminated dual regulation of air emissions that had been previously regulated by both NRC and EPA.

4. CURRENT EFFLUENT RELEASES FROM NUCLEAR INSTALLATIONS

The United Nations Scientific Committee on the Effects of Atomic Radiation (UNSCEAR) has regularly collected data and evaluated radioactive effluent releases from nuclear installations. Based on the reported data UNSCEAR derives e.g. average annual releases of radionuclides from these installations. These averages are used to estimate the consequent exposures for each type of reactor.

The evaluation of release made by UNSCEAR is based on data reported by countries having nuclear facilities. The reported data is substantial and comprehensive. There is, however, no established common report format, which means that data are not always fully compatible. Where some data were of uncertain quality, these may have been omitted in the evaluation.

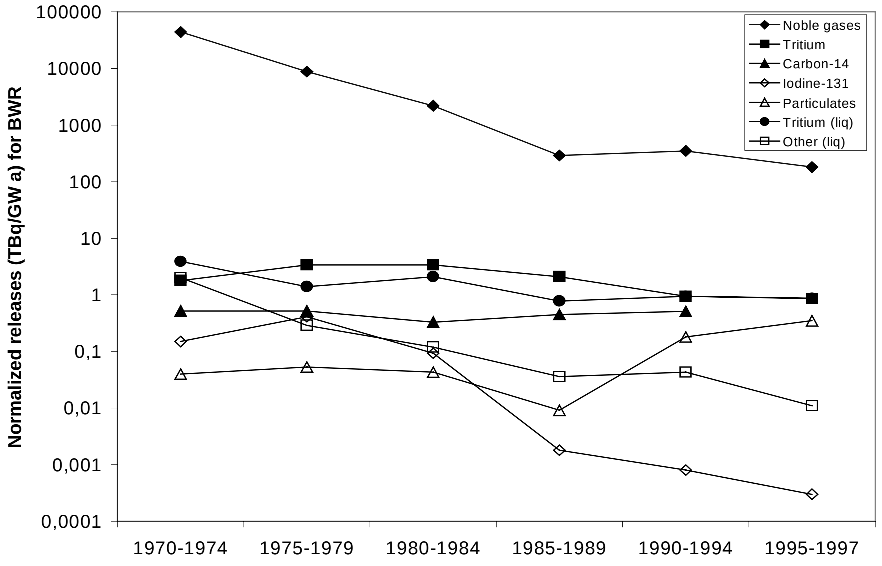
Effluent releases from nuclear power reactors

The average annual releases of radionuclides from nuclear power reactors are grouped according to the type of reactor (PWR, BWR, GCR, HWR, LWGR, FBR). The longer-term trends for PWRs, BWRs, GCRs and HWRs based on average normalised releases of radionuclides from each type of reactor, are shown in Figure 1 (UNSCEAR 2000).

For PWRs and BWRs, it can be seen that these normalised releases are either fairly constant or decreasing. An exception from these trends is the releases of radioactive particulates to air from BWRs. A closer look at the data shows that this deviation reflects the operation of one specific reactor and is not characteristic for all BWR reactors.

Most GCRs are in the UK. These are either Magnox reactors (the older type) or Advanced Gas-cooled Reactors (AGRs – the more modern type). Magnox reactors have natural uranium metal fuel in magnesium alloy (“Magnox”) cladding with a graphite moderator and carbon dioxide primary coolant. AGRs have enriched uranium dioxide fuel in stainless steel cladding with a graphite moderator and carbon dioxide primary coolant. Each type of reactor has a different characteristic set of discharges.

Figure 1. **Time trends in normalised releases of radionuclides for PWR, BWR, GCR and HWR reactors**



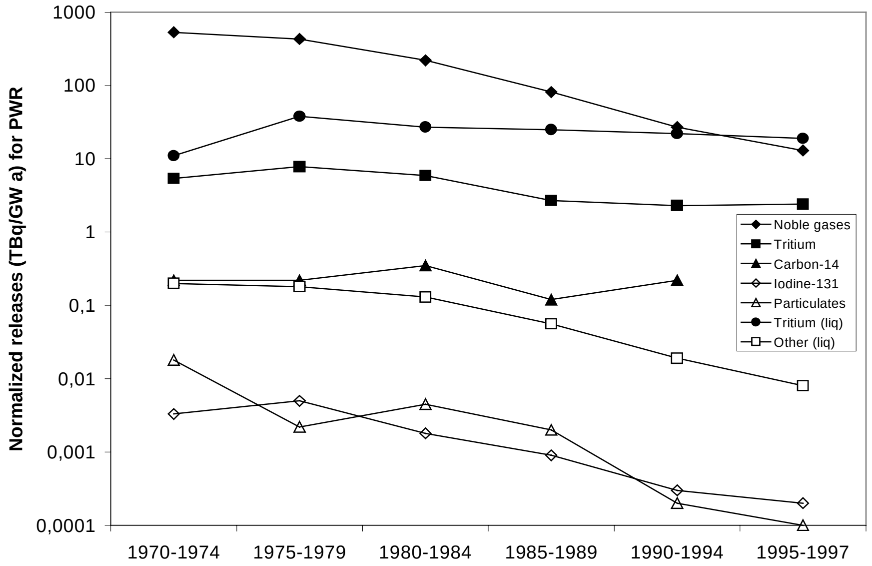
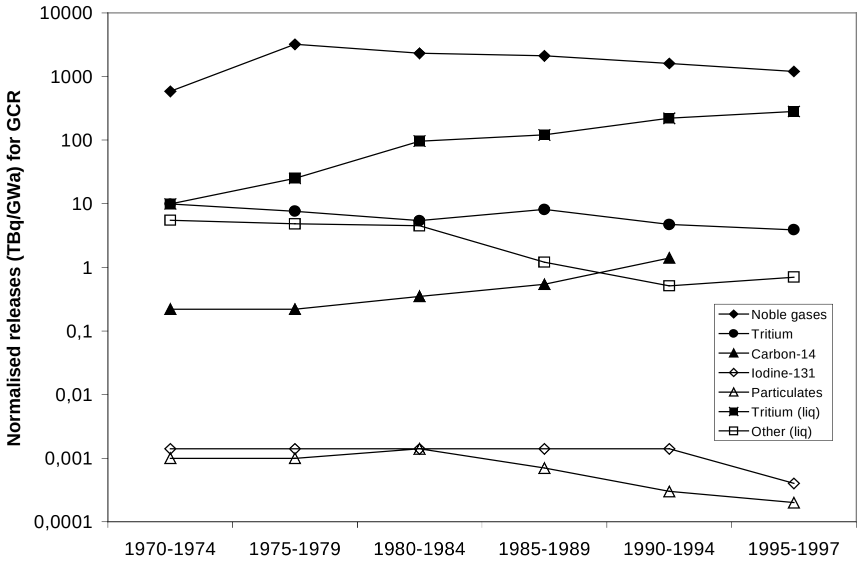
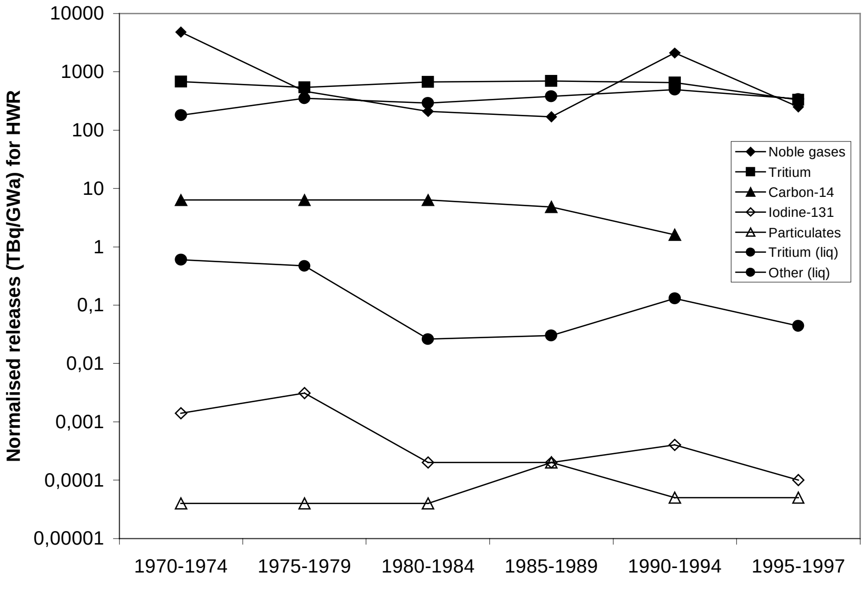


Figure 1. **Time trends in normalised releases of radionuclides for PWR, BWR, GCR and HWR reactors** (cont.)





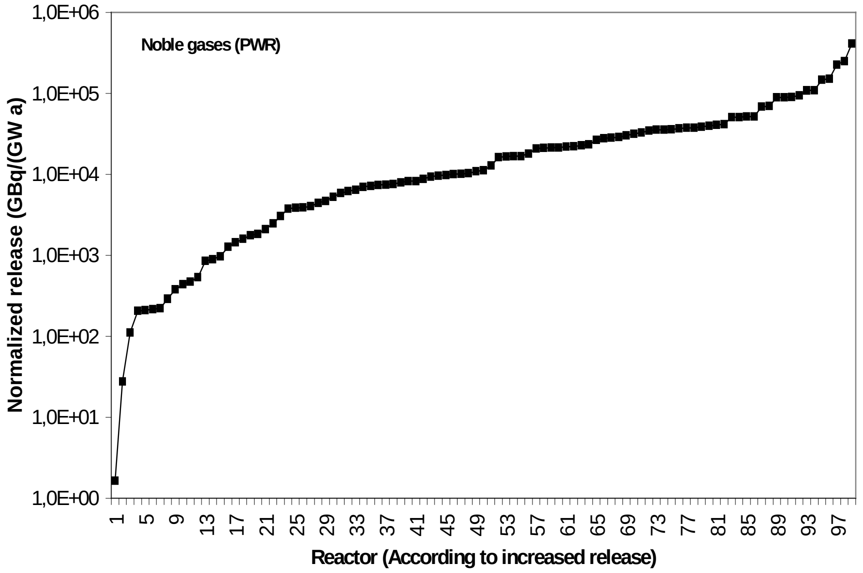
For the Magnox power stations, the position is further complicated because four of those still operating (Calder Hall, Chapelcross, Dungeness A and Sizewell A) have steel pressure vessels while the remaining two (Oldbury and Wylfa) have concrete pressure vessels, and also because all but Wylfa (the largest) store their spent fuel under water in cooling ponds before trans-shipment for reprocessing, while Wylfa has dry stores. These design differences affect discharges. In particular, the steel pressure vessel stations make relatively large gaseous discharges of argon-41, resulting from neutron activation of the cooling air passing between the pressure vessels and the surrounding concrete biological shield, while for the Magnox stations with spent fuel cooling ponds the regulators have deemed it necessary to place a specific limit on aqueous discharges of caesium-137.

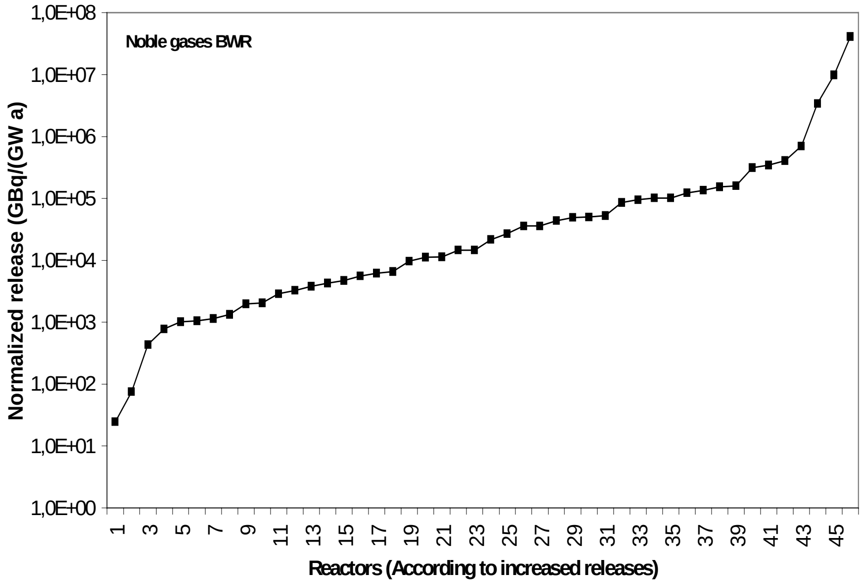
All the AGR power stations have concrete pressure vessels and all store their spent fuel under water in cooling ponds before trans-shipment for reprocessing.

The analysis of release data for the last available five-year period, 1990-1994, in UNSCEAR 2000 shows that there are substantial differences in the releases between individual reactors. This may be caused for example by the integrity of the fuel, the waste handling systems, and procedures and maintenance operations conducted. Normalised releases of noble gases, tritium, iodine-131 and particulates in airborne releases and tritium and other radionuclides in liquid effluents for individual reactors all show a wide range in data. For radionuclides other than tritium in liquid effluents the range is more than eight orders of magnitude. As one example, the normalised releases of noble gases for PWR and BWR reactors are shown in Figure 2.

To some extent the wide distributions of data may be explained by differences in reporting, in the case of noble gases particularly the extent to which short-lived isotopes are reported. Various measuring practices at the reactor stations may also contribute to the large spread in data.

Figure 2. **Normalised releases of noble gases for 99 PWRs and 46 BWRs**





Effluent releases from nuclear reprocessing plants

The routine releases from the main commercial fuel reprocessing facilities in France, Japan and the United Kingdom have been largely in liquid effluents to the sea. The average normalised releases per unit of energy generated are summarised in Figure 3. It can be observed that the releases to both air and sea of most radionuclides have been decreasing over the long term. This is particularly so for the releases of ruthenium-106, strontium-90, and caesium-137 to the sea and for caesium-137 and iodine-131 to the air.

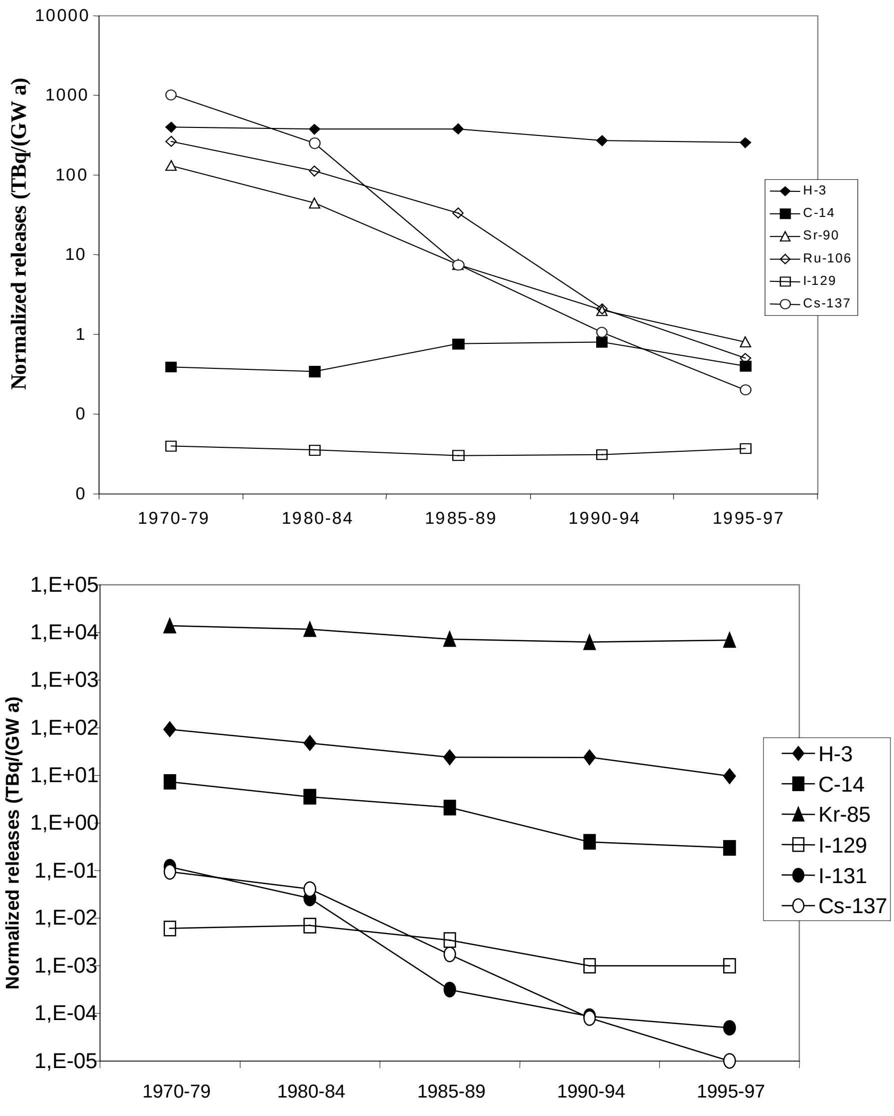
Dose estimates

For nuclear power reactors, the concentrations of the released radionuclides in the environment are often too low to be measurable except close to the nuclear facility and then only for a limited number of radionuclides. Therefore, dose estimates for the population have to be based on modelling the atmospheric and aquatic transport and environmental transfer of the released radioactivity and then applying a numerical dose model. UNSCEAR applies the dose assessment procedures to a hypothetical model site with representative environmental conditions. UNSCEAR primarily reports the normalised collective effective doses per unit electrical energy generated (manSv/GWa) from radionuclides released from the various stages of the nuclear fuel cycle. The longer-time trends show decreases attributable to reductions in the releases from reactors and fuel reprocessing plants. Compared to the earliest assessment period, 1970-1979, the normalised collective effective doses during 1995-1997 have decreased by much more than an order of magnitude for releases from reprocessing plants and by a factor of 7 for releases from reactors.

For the reactor model site, the annual average effective doses to individuals are calculated from the release data assuming that the total collective dose for a reactor type exposes a single local population group (population density 400 per km^2 up to 50 km from the site). With this assumption, the annual doses are 5 μSv for PWRs and GCRs, 10 μSv for BWRs and HWRs, 2 μSv for LWGRs and 0.04 μSv for FBRs. According to UNSCEAR, individual doses reported from a number of reactor sites are in the range 1-500 μSv.

For fuel reprocessing, the average effective dose commitment to a single local population ($3.1\ 10^6$ persons within 50 km) would be about 10 μSv per year of operation. This dose is delivered over a longer-term, especially from C-14.

Figure 3. **Time trends in releases of radionuclides in airborne and in liquid effluents from fuel reprocessing plants**



5. CHARACTERISATION OF EFFLUENT RELEASES FROM EXISTING NUCLEAR INSTALLATIONS AND ABATEMENT TECHNIQUES

The purpose of this chapter is generally to characterise effluent releases from existing nuclear installations, mainly those from nuclear power plants, and to discuss available techniques for effluent management.

Characterisation of effluent releases from existing nuclear power plants

The following analysis is based on generic effluent release data from a modern 1 300 MW(e) nuclear power plant and a reprocessing facility, as they were developed for the NEA publication on the *Radiological Impact of Spent Nuclear Fuel Management Options* (OECD/NEA, 2000). The effluent release data are given in Annex 3.

Analysing the given effluent release data from nuclear power reactors, it appears that, in summary, modern nuclear power plants discharge, mainly, the longer-living radionuclides tritium, carbon-14 and krypton-85 in amounts which can be detected in the environment. The (very low) doses to the public are dominated by the discharge of carbon-14. Currently, there are no abatement techniques in place to reduce the discharges of tritium and carbon-14. There is also no end-of-pipe abatement technology for krypton-85, however, radioactive noble gases can be contained in the nuclear fuel elements, and discharges are optimised by appropriate fuel management. For gas cooled reactors, these statements need to be qualified somewhat, as for example on these reactors, carbon-14 dominates collective dose but does not dominate critical group dose.

Regarding the effluent releases of a typical nuclear power plant, the following detailed statements can be made:

- Actinides can only be detected at extremely low concentrations in gaseous and liquid discharges from nuclear power plants.

- Activation and fission products are concentrated and contained, and only very low activities are discharged via gaseous and liquid effluents. In general, these radionuclides cannot be detected in environmental samples around a nuclear power plant. Based on model calculations, these releases result in very low doses to the population. On gas-cooled reactors (as on other types of reactor) the aim is to contain fission products in the fuel. Reactor gas circuits have sensitive fuel failure detection equipment and any failed fuel is quickly removed. Hence the level of fission product contamination of reactor gas circuits is kept very low. (The only exception to this is tritium produced by ternary fission, which tends to diffuse through fuel cladding.)

  Various measures are adopted to prevent fission products from failed fuel leaking into fuel cooling ponds and to clean up the ponds if such leakage does occur. Nevertheless, some discharge of fission products does occur in liquid effluents, especially from the Magnox stations. The principal radionuclide concerned is caesium-137, which is subject to specific limits on Magnox stations with cooling ponds and is the main contributor to public dose arising from liquid discharges from these stations. It can be detected in relevant environmental samples (as sometimes can cobalt-60 and caesium-134).

  Tritium, carbon-14, sulphur-35, argon-41, iron-55 and cobalt-60 are among the main activation products created in gas cooled reactors. Iron-55 and cobalt-60 are primarily associated with particulate matter and are largely filtered out of discharges. The other activation products identified here are essentially discharged unabated, although in some cases there may be a transfer from the gaseous to the liquid phase, where discharges have a lower radiological impact. Tritium, carbon-14 and sulphur-35 can sometimes be detected in environmental samples.

- Noble gases are discharged with gaseous effluents, especially during refuelling outages. In general, radioactive noble gases can not be detected in environmental samples around a nuclear power plant. They give rise to low doses to the population. The radioactive noble gas krypton-85 is the only radionuclide with a half-life longer that a few days (10.7 years). It is detectable, in very low concentrations, in the atmosphere. Argon-41 discharges from gas-cooled reactors constitute a special case. For Magnox power stations with steel (rather than concrete) reactor pressure vessels it is produced by neutron activation of cooling air. Direct radiation from the argon-41 plume results in a significant fraction of the low dose which the most exposed members of the public receive. For all Magnox and AGR power stations, argon-41 is also produced by activation of trace quantities of argon in the carbon dioxide coolant, which then leak with the coolant into the environment.

- Tritium from nuclear power plants is discharged without treatment via liquid and gaseous releases to the environment. Low concentrations of tritium can be found in environmental samples, including a contribution from naturally-occurring tritium. Due to the very low dose factor of tritium, the doses to the public resulting from these concentrations are low. In PWRs and BWRs, the amount of tritium produced is directly related to the power production. In gas cooled reactors, the amount of tritium produced is related to the amount of moisture in the reactor gas circuit, which varies. Thus, it does not simply correlate with power production.

- Carbon-14 from nuclear power plants is discharged without treatment via liquid and gaseous releases to the environment. Low concentrations of carbon-14 can be found in environmental samples, including a contribution from naturally-occurring carbon-14. Due to the reduction of other radioactive effluent releases, carbon-14 discharges contribute a major fraction of the (very small) total collective dose to the public from nuclear power plants.

There is an issue of prioritisation in the optimisation process. A technique that reduces the quantity released of one radionuclide, but at the cost of increasing the quantity released of another radionuclide, will lead to the question of how to optimise and what priorities to give to different considerations such as the impact on humans, the impact on the environment, the impact now and the impact in the future.

Available techniques

Best available techniques for effluent management include both the technology used and the way in which the nuclear installation is designed, built, maintained, operated and decommissioned. These factors must be taken into account when designing new nuclear installations both to optimise the efficiency of plant processes and to maximise protection of the environment. This might particularly be true for new generations of nuclear reactors, such as the US Westinghouse 1 000 MW advanced passive reactor (AP1000) or the South African 120 MW pebble bed modular reactor (PBMR), both of which rely upon a modular design that can be rapidly constructed or expanded to meet local energy needs. However once nuclear plants are built there are generally fewer opportunities to change the design of the process and so the focus of optimisation shifts towards improvements in abatement technology.

Problems of design inflexibility are worse for older nuclear plants which were constructed in the 1950s and 1960s when permitted standards of environmental protection were different than today. Inevitably the costs of abating discharges from these old plants are much higher than for new plants, where recycling and recovery can be "designed-in" as an intrinsic part of the nuclear process.

A wide range of abatement technologies are potentially available for reducing or eliminating emissions, which are often used in combination to achieve very high decontamination factors (DFs). Examples include:

Liquid abatement

- Chemical precipitation
- Hydrocyclone centrifuging
- Cross-flow filtration
- Ion exchange
- Reverse osmosis
- Ultrafiltration
- Evaporation

Gaseous abatement

- Electrostatic precipitation
- Cyclone scrubbing
- Chemical adsorption
- HEPA filtration
- Cryogenics

Liquid abatement

Chemical precipitation is used as a coarse abatement technology to remove radionuclides dissolved in aqueous solution such as caesium or plutonium, usually by addition of an alkali to increase pH so that the radionuclides are co-precipitated as insoluble carbonates or hydroxides. Ion exchange resins are used to polish the treated effluent removing very low levels of contamination. The treated liquid effluent is filtered and passed through an ion exchange column which uses cation exchange resin to remove strontium, caesium or cobalt cations, replacing them with sodium or calcium. In combination, precipitation, filtration and ion exchange can achieve high DFs of typically between 10^3 and 10^6.

Liquid effluents may also contain insoluble radionuclides, usually reactor corrosion products or metal oxides of differing particle sizes, which are suspended in solution. These cannot be removed by precipitation or ion exchange and require the use of physical separation technologies such as centrifuging and cross-flow filtration. Hydrocyclone centrifuges remove solid radioactive particles by rapidly rotating the liquid effluent in a vortex. Centrifugal forces cause the particles to migrate towards the wall of the hydrocyclone separating them from the effluent. The efficiency of filtration depends upon particle size and in practice several hydrocylones may be used in series to polish the effluent. Cross-flow filtration technology is sometimes used as pre-treatment stage before hydrocycloning. Two separate fluid loops are connected by a cross-flow filter which separates a primary waste effluent stream from a secondary decontaminated effluent stream flowing in the opposite direction. The primary liquid effluent stream flows under pressure through a serious of porous filter tubes. Clarified permeate passes through the walls of the filter tubes leaving a greatly increased level of suspended solids in the primary effluent. At a certain velocity shear forces in the fluid flow between the primary and secondary loops prevent the formation of solid filter cake on the tube walls improving separation efficiency. In combination cross-flow filtration and hydrocycloning can achieve high particulate DFs.

Reverse osmosis, ultrafiltration and evaporation technologies are used for removing very low levels of contaminants from liquid effluents usually before final discharge into the environment. Both reverse osmosis and ultrafiltration rely on passing very clean effluent through a sensitive permeable membrane under high pressure. The membrane retains and concentrates molecule-sized particles while clean water and dissolved salts pass through. In combination these techniques offer close-to-zero emission technology and with ambient temperature evaporation can completely eliminate liquid discharges of most nuclides. AWE Aldermaston in the UK is developing a system using hot closed loop evaporation, ultrafiltration and ambient temperature evaporation to completely eliminate plutonium discharges into the River Thames (part of the London drinking water supply) by 2005.

Gaseous abatement

Modern gaseous abatement techniques mainly focus upon three technologies; dry high efficiency particulate aerosol (HEPA) filtration to remove particulate actinide aerosols; wet gas scrubbing to remove soluble fission product particles and some gases such as carbon dioxide; and carbon adsorption technologies to remove volatile chemically reactive gases such as iodine. Banks of HEPA filters are commonly used to remove radioactive solid particle aerosols in dry atmosphere environments. HEPA filters achieve DFs of 10^7 when several filters are arranged in series and parallel combinations. Wet scrubbers are used to treat off-gases from nuclear process plants or radioactive waste incinerators. The scrubbers trap radioactive particulate aerosols and gases by passing the gas stream through a vertical column which is continuously washed with recycled aqueous sodium hydroxide solution cascading from the top of the scrubber to its base. Volatile iodine fission products from nuclear reactors are abated using carbon filter beds. The filter beds are porous which provide a very high effective surface area for adsorbing the iodine gas. These technologies are relatively mature and it is unlikely that new techniques will significantly enhance their effectiveness.

6. THE CONCEPTS "AS LOW AS REASONABLY ACHIEVABLE (ALARA)" AND "BEST AVAILABLE TECHNIQUES (BAT)"

One of the basic principles of the system of radiological protection is Optimisation, asking for exposures to be kept "as low as reasonably achievable (ALARA)", economic and social factors taken into account. In recent years, the concept "best available techniques (BAT)" appeared in various contexts and became also associated with effluent release optimisation.

In this chapter, the concepts ALARA and BAT are discussed in the context of effluent release optimisation.

As low as reasonably achievable (ALARA)

The system of radiological protection, as described in ICRP Publication 60, is based on the three basic principles: justification of a practice, optimisation of protection and individual dose and risk limits. The optimisation of protection for practices is described as

> "In relation to any particular source within a practice, the magnitude of individual doses, the number of people exposed, and the likelihood of incurring exposures where these are not certain to be received should all be kept as low as reasonably achievable, economic and social factors being taken into account. This procedure should be constrained by restrictions on the doses to individuals (dose constraints), or the risk to individuals in the case of potential exposures (risk constraints), so as to limit the inequity likely to result from the inherent economic and social judgements."

This description of the optimisation of protection, introducing the term ALARA, focuses on individual doses and refers to risks assessed using the dose/risk relationship recommended by the ICRP. ALARA has proved to be an effective tool for managing human risks after low dose exposures taking into account individual doses, the number of exposed individuals and the likelihood that an exposure situation will occur.

Following ICRP recommendations, a linear relationship between the risk of harmful effects and the radiation dose is assumed at low doses. Theoretically, the dose can always be further reduced. However, this will lead to an increased cost. Accordingly, there is an optimum protection level in terms of additional risk and cost.

In accordance with internationally agreed Basic Safety Standards, the dose limit for members of the public is 1 mSv per year from all contributing artificial radiation sources. Taking into consideration that an individual may be affected by dose contributions from more than one source (facility), a dose constraint for a particular site (or all facilities located in the same geographically delimited area) is set. This dose constraint is less than 1 mSv/y. The doses from radioactive releases to the most affected individuals must be below the dose constraint.

The most exposed members of the public are defined as the critical group as described in ICRP publication 60. There are different methods for setting up the critical group. One is to identify the critical exposure pathways for each radionuclide and then identify the exposed individuals.

Best available techniques

The concept of BAT is used in the OSPAR convention for the protection of the marine environment of the North-East Atlantic for all types of industrial installations including nuclear installations. The European Union has a set of common rules on permitting for industrial installations, which are set out in the *Integrated Pollution Prevention and Control (IPPC) Directive of 1996*, which is concerned, in essence, with minimising pollution from various point sources throughout the European Union.

The IPPC Directive offers in Article 2 the following definition of best available techniques for all types of industrial installations:

> **"best available techniques"** shall mean the most effective and advanced stage in the development of activities and their methods of operation which indicate the practical suitability of particular techniques for providing in principle the basis for emission limit values designed to prevent and, where that is not practicable, generally to reduce emissions and the impact on the environment as a whole.

- **“techniques”** shall include both the technology used and the way in which the installation is designed, built, maintained, operated and decommissioned;
- **“available”** techniques shall mean those developed on a scale which allows implementation in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages, whether or not the techniques are used or produced inside the Member state in question, as long as they are reasonably accessible to the operator;
- **“best”** shall mean most effective in achieving a high general level of protection of the environment as a whole.

The essence of IPPC Directive is that operators should choose the best option available to achieve a high level of protection of the environment taken as a whole. This, together with consideration of local circumstances, provides the main basis for setting emission limit values. The BAT approach ensures that the cost of applying techniques is not excessive in relation to the environmental protection they provide. It follows that the more environmental damage BAT can prevent the more the operator can justify spending before the costs are considered excessive.

Where there is a choice, the technique that is best overall will be BAT on the assumption that it is an “available technique”. There are two key aspects to the availability test:

- what is the balance of costs and advantages? This means that a technique may be rejected as BAT if its costs would far outweigh its environmental benefits; and
- can the operator obtain the technique? This does not mean that the technique has to be in general use. It would only need to have been developed or proven as a pilot, provided that the industry could then confidently introduce it.

The basic principles for determining BAT involve identifying options, assessing environmental effects and considering economics. The principles of precaution and prevention are also relevant factors for BAT determinations.

Relationship between ALARA and BAT

ALARA and BAT are both optimisation concepts, complementing each other with the aim of limiting doses to humans, possible effects on non-human species, and effluent releases of radioactive substances. With a view to the consequences to human health, the limitation of effluent releases will be driven by the optimisation of estimated radiation doses to individuals using ALARA. In situations where humans are not directly affected or not the primary protection target, the optimisation of effluent releases will be based on the application of "best available techniques".

The concept of ALARA focuses on the optimisation of doses to individual members of the public taking into account all possible sources which could have an impact on an individual. ALARA is impact-oriented and represents therefore the concerns of individuals (members of the public and nuclear workers). ALARA as it is currently formulated by ICRP focuses on optimising the protection of humans, not explicitly considering possible effects on non-human species.

ALARA is applied to all sources potentially affecting an individual, whereas BAT applies and focuses on a single source of effluent releases, for example, on each reactor within a nuclear power plant. BAT is plant-oriented, and represents therefore an optimisation concept for operators and regulators.

In general, the application of BAT to every individual source by operators and regulators achieves ALARA with respect to the environment as a whole.

Both ALARA and BAT are moving targets because what are currently regarded as "reasonably achievable" and "best available" change with developing societal perceptions and advancing techniques.

Objectives for the optimisation of effluent releases

The management of effluent releases from nuclear installations can make use of the concepts ALARA and BAT in various ways. The optimisation process at a single nuclear installation or source aims to achieve individual and/or collective doses to members of the public and to workers that are ALARA. The application of BAT at a single nuclear installation or source aims at limiting radioactive effluent releases from that source. Implementing BAT at all nuclear installations and sources which may have an impact on a particular ecosystem aims to achieve a reduction of concentrations of radionuclides in the environment. A holistic approach to protection of the public, workers, and the environment may include all of these uses of ALARA and BAT, taking due account of potential accident situations.

The first two approaches focus on the sources of radioactive substances and asks for an optimisation of effluent releases from each nuclear installation, either with a dose objective or with an objective for the concentration of radioactive substances in the effluents. The environmental approach, the third approach, focuses on the status of the environment by monitoring concentration of radionuclides in the environment, and demands for a reduction of any additional input, considering all possible sources discharging to the monitored compartment of the environment. The “source related approach” and the “environmental approach” complement one another and are by no means mutually exclusive.

Reference values and target values – an application of BAT to nuclear facilities

In the Swedish regulations concerning releases from nuclear facilities, BAT is defined as "the most effective measure available to limit the release of radioactive substances and the harmful effects of the releases on human health and the environment, which does not entail unreasonable costs".

The BAT concept is applicable to all sources of radioactivity at a nuclear facility. However, in the regulations nuclear power reactors are specially emphasised by introducing so called reference values and target values for the releases of radioactive substances. The reference value should show "the release level that is representative for optimum use and proper functioning of systems important to the limitation of radioactive releases from nuclear power reactors". Decisive factors for defining reference values are operating experience and knowledge of the size of releases, in a historical perspective. Reference values can also comprise indicators of the efficiency of the effluent treatment systems. The reference values will be different for different reactors. It is important to point out that these values do not comprise limit or guidance levels, but must be considered to be a measure of the normal release-limiting capability of different reactors. The values can consequently be changed, for example, when there is a change in release-limiting systems.

Taking the BAT concept into consideration the facility shall also establish target values for each nuclear power reactor. The target value should show "the level to which the radioactive releases from nuclear power reactors can be reduced during a certain given period of time".

The difference between reference values and target values is that reference values describe the current situation whereas target values indicate what can be achieved in the future. For some facilities, reference values and targets can be relatively similar since what may be suitable in accordance with the BAT principle has already been achieved. However, in the case of aged reactors, the situation may be completely different.

Application of BAT to nuclear facilities in the United Kingdom

In the UK, the regulation of radioactive waste discharges and disposals is governed by two optimisation concepts which, taken together, are regarded as the equivalent of BAT. These concepts are Best Practicable Environmental Option (BPEO) and Best Practicable Means (BPM). If BPEO and BPM are applied to a set of processes, facilities and methods of operation, then it is considered that radiation risks to the public and the environment will conform to the ICRP principle of being as low as reasonably achievable (ALARA). BPEO has been defined as:

The outcome of a systematic consultative and decision making procedure which emphasises the protection and conservation of the environment across land, air and water. The BPEO procedure establishes, for a given set of objectives, the option that provides the most benefits or least damage to the environment as a whole, at acceptable cost, in the long term as well as in the short term.

BPM has been defined as follows:

BPM is a term used by the Environment Agency and the Scottish Environment Protection Agency in authorisations issued under the Radioactive Substances Act. Essentially, it requires operators to take all reasonably practicable measures in the design and operational management of their facilities to minimise discharges and disposals of radioactive waste, so as to achieve a high standard of protection for the public and the environment. BPM is applied to such aspects as minimising waste creation, abating discharges, and monitoring plant, discharges and the environment. It takes account of such factors as the availability and cost of relevant measures, operator safety and the benefits of reduced discharges and disposals.

BPEO is about global optimisation (for example, of an entire facility) with respect to its environmental impact, whereas BPM is about optimising individual waste streams. The practical implementation of BPEO and BPM is highly case dependent.

7. FACTORS INFLUENCING DECISIONS ON EFFLUENT RELEASE OPTIONS

Both technical and policy factors will affect decisions on effluent releases. The eventual decision will need to balance waste management (including operator dose and risk from fault conditions), possible transboundary effects, take account of sensitive locations, have regard to detectability and monitoring and most certainly the radiological impact of the discharges.

Waste management

A general principle applied in radiological protection and waste management is a preference for options which focus on "concentration and containment" of radioactivity over "dilute and disperse". The following factors, however, need to be considered in any options' evaluation: the possible need to store solid or liquid wastes in conditions which are not passively safe and which could give rise to increased operator doses and accidental discharges. The treatment of raw waste into a passively safe form should not be delayed.

This is particularly important for radionuclides which have high radiological impact, e.g. transuranics, cobalt-60, strontium-90 and caesium-137, and high degree of treatment and abatement is necessary for effluent streams containing these radionuclides. For a small number of radionuclides, retention in solid waste poses other problems for increased doses to the worker, and for long term waste management, which need to be taken into account. Tritium is produced in numerically large amounts in nuclear power plants and reprocessing facilities. It is practically very difficult to reduce discharges of tritium. The radiological impact of tritium is relatively small and radiological impact of discharges will usually be very low. When discharged into water tritium diffuses and dilutes quite quickly after release, although organically bound tritium (OBT) has been detected near to radiopharmaceutical production sites. However OBT is not normally discharged from nuclear fuel cycle facilities.

Long term waste management and disposal of wastes containing long lived and environmentally mobile radionuclides such as chlorine-36, technetium-99 and iodine-129 can, in the far future, result in releases from disposal sites. When considering management of effluent streams containing these radionuclides, consideration should be given as to balancing controlled releases into the environment at the present time, with predicted releases, in the future, from wastes in a repository.

Decisions to treat wastes need also to have regard to potential worker exposures, both from operation of waste treatment plant and from long term storage of the solid wastes and residues which will be produced.

Transboundary effects

Releases that may have transboundary effects may take the form of aerial or stack emissions or discharges of liquid effluent to river or coastal waters. Where nuclear facilities are located close to another country or share a water mass, then there exists the potential for some effect arising out of the operation of these facilities to be observed in the neighbouring country. Such a transboundary effect might be defined as the detectable presence of radioactive material in the neighbouring country. Once such contamination has taken place, then it is likely to enter the food chain in that country and give rise to public radiation exposure and associated risk for the most exposed individual. Though difficult to quantify there also exists the potential for an economic impact on the neighbouring country where the perception of contaminated agricultural or mariculture produce may lead to a diminution in product demand. Though not exclusively a transboundary effect, such contamination may also have psycho-social effects.

Locations which may be vulnerable to transboundary effects include the borders between European countries and also between the United States and Canada from nuclear reactor emissions, and reprocessing activities causing discharges into the Irish Sea; the English Channel, and rivers which feed seas such as the Mediterranean and the Kara Sea. Discharge reductions from these sources through the application of BAT will have the effect of decreasing environmental concentrations of some radionuclides in biota, water and sediments over time. This process may be delayed in some environments due to remobilisation from sediments or in-growth as is the case with americium-241 in the Irish Sea where the radioactive inventory is still increasing as a result of in-growth from the decay and reduction in inventory of previously discharged plutonium-241 (see the case study).

Transboundary Effects Case Study
Discharges from Reprocessing Activities at Sellafield and Cap de la Hague

Discharges of radioactivity from reprocessing activities at Sellafield in the UK have taken place since 1952 and from Cap de la Hague in France since 1966. Marine environmental monitoring studies at Sellafield have shown that particle reactive nuclides such as the isotopes of plutonium, americium and neptunium are quickly removed from the water column and are deposited in the muddy sediments of the eastern Irish Sea. However a fraction of these discharges exist in a soluble chemical form that is more mobile and find their way to the western Irish Sea and the North Channel and beyond. More soluble radionuclides such as caesium-137 and technetium-99 move largely with the general water movement west and north migrating to the North Sea between Scotland and the Shetland Islands.

Radionuclides transported in this way give rise to detectable concentrations in the water, biota and sediments in sea areas at long distances from the original release site. Taking into account the radioactive decay of caesium-137 with a half life of 30 years, a time trend analysis of caesium-137 concentrations in the Barents Sea closely matches the pattern of releases from Sellafield with a time delay of approximately 5 years. The rate of introduction of caesium-137 into the Barents Sea has been estimated at 200-300 TBq/a.

Waters entering the North Sea from the English Channel via the Straits of Dover contain releases from the reprocessing plant at La Hague.

Inputs to the North Sea find their outlet through the Norwegian Channel. They are then transported northward by the Norwegian coastal current before branching off Northern Norway. One branch flows eastwards into the Barents and Kara Seas while the other becomes the west Spitzbergen current.

Clean up and decommissioning

Remediation of the legacy from past practices may produce certain levels of radioactive effluents for limited periods. When considering how best to manage these it is important to bear in mind that discharges may need to be tolerated at certain levels in the interests of treating waste into a passively safe state and cleaning up former facilities.

Measurement technologies

Technologies to monitor the quantities of radionuclides in discharge emissions and the concentration of radioactivity in the receiving environment are becoming an increasingly important component of the optimisation of effluent releases. Environmental protection legislation often sets emission limit values (ELV) or minimum environmental quality standards (EQS) which must be achieved to ensure that the application of BAT delivers environmentally acceptable results. Technology to monitor discharges at source is especially important where the objective is to achieve close-to-zero emissions.

In Germany, for example, detection limits for environmental monitoring are related to radiation exposure limits for members of the public. The detection limits must ensure, that dose contributions from external radiation, ingestion or inhalation of one third of the dose limit to the public (0.1 mSv respectively) can be recorded. Because exposures typically arise from several different radionuclides, the detection technology must be capable of detecting each individual radionuclide at a detection limit of 0.01 mSv per annum. In Sweden members of the public are limited to an exposure of 0.1 mSv per annum and, like Germany, individual radionuclides from emissions must be capable of being detected at 0.01 mSv per annum. Actual doses to members of the public from modern PWR nuclear power plants are typically only 0.001 mSv per annum. The main contributors to radiation exposure are carbon-14 (60%), tritium (30%) and krypton-85 (20%) which are not abated from reactor emissions.

In the UK, site-based discharge limits, usually in the form of an annual emission limit for key substances, are the most important regulatory control mechanism because they directly limit the total amount of pollution that may be released into the environment from an installation. Such annual emission limits form the basis of pollution reporting requirements under UK IPPC and the Radioactive Substances Act (RSA). The aim is to review them every 4 years.

Monitoring environmental radiation

For monitoring environmental radiation independently of nuclear installations detection limits must be defined which will allow the detection of variations in environmental radioactivity in time and space. As in normal circumstances concentrations of artificial radionuclides in the environment are very small, the aim to measure actual concentrations often can only be met by employing time consuming and expensive analytical procedures.

The EU has tried to solve this problem for its annual reports on environmental activity levels by asking for information from its member states within two different networks.

- Within the "dense network" data from a great number of sampling locations in the European Union are compiled to monitor levels of radioactivity for radiological protection purposes. In order to facilitate the presentation of the results, it was agreed to use uniform reporting levels, which were derived on the basis of the annual dose limit for the public. This limit, which equals an effective dose of 1 mSv, decreased by a factor of thousand, i.e. 1 μSv, was regarded as having no radiological significance (1 μSv representing a radiological risk of 5.10^{-8} per year). Values below reporting level are considered to lead to an annual dose less than 1/2000 of the natural background. Today most values measured in the "dense network" are below reporting level.
- The "sparse network" was designed to monitor trends in radionuclide concentrations over time. It requires data from a small number of representative sampling locations where high sensitivity measurements of radionuclides known to be present in the environment are performed. For these measurements no required reporting levels were defined, as actual concentrations should be measured. Yet for practical purposes the EU has meanwhile unofficially introduced reporting levels which should be 1% of those for the dense network.

In Germany, the nation-wide programme for monitoring environmental radioactivity was initiated much later than the programme in the vicinity of nuclear installations. The requirement for its detection limits was, that widespread changes in environmental radioactivity should be detected without asking for unreasonably expensive or time consuming measurements. For most radionuclides the resulting detection limits were not substantially different from those for the environmental monitoring programme for nuclear installations. Consequently identical detection limits for identical measurements in both programmes have been agreed upon for the future.

Additional considerations

Actual effluent releases from nuclear power plants give rise to calculated doses of the order of a few μSv, which are considerably below the defined dose constraints of a few hundred μSv. Reference values, usually set in terms of activity discharged, allows to control the doses in this margin between actual (realistic) discharges from a specific practice and the licensed discharge limits. This margin is sometimes referred to as “headroom”. Without additional requirements for optimisation, this “headroom” might allow “bad practice” to be authorised. A further reduction of discharges may be achieved by either requiring the application of best available techniques or by a reduction or minimisation of the headroom (or by both of these means).

Regulatory tools in Spain

During operation, licensees have to demonstrate that every reasonable effort is made, from the generation of wastes to the operation proceedings of the effluent treatment systems, to reduce releases and to keep the radiological impact as low as is technically and economically feasible. They are required to develop a Continuous Safety Assessment Programme (CSA) taking into account the evolution of norms, the progress in technology (BAT), and the operational experience. Operators have to consider also the applicability of current standards and new regulations applied in the country of origin of the project. Information on design modifications must be submitted to the Regulatory Authority on a periodic basis.

Licensees are also required to perform a Periodic Safety Review (PSR) programme, usually on a ten years basis, intended to analyse the global behaviour of the plant over a long period, to guarantee that lessons learned from the analysis of the operational experience have been properly implemented and to evaluate the applicability to the facility of relevant changes in the new generation plants. The documentation submitted and the results of the evaluation performed by the Regulatory Authority are normally taken into account in the renewal of the operating permits. The effluents control and environmental monitoring programmes are included among the programmes to be considered in the PSR. The Regulatory Authorities establishes “Reference Levels” (RL) for liquid and gaseous effluents, set up in terms of activity for groups of nuclides that indicate optimal operation of the reactor in terms of radioactive wastes generation and discharges into the environment. These values can be reviewed after an analytical examination of:

- the history of discharges and emissions and their relationship to the authorised limits:
- the status of the current techniques and operating procedures adopted by the facility in radioactive waste management (BAT).

8. DECISON-AIDING STRATEGIES FOR EFFLUENT RELEASE OPTIONS

In the past, the optimisation of effluent releases from nuclear plants has been driven by prospective assessments of stochastic health effects on members of the public potentially exposed to radioactive emissions. This health-driven approach to protection has resulted in the development of nuclear abatement systems which concentrate and contain gaseous and liquid emissions converting them into solid waste forms for long term storage.

For nuclear installations, the concept of "best available techniques" as a management tool for optimising effluent releases is rather new, and guidance material is therefore limited. In order to give an example of how the concept of BAT could apply within the nuclear sector, the following two subchapters try to develop a decision-aiding strategy for effluent release optimisation based on factors indicating the application of "best available techniques".

Nuclear BAT management factors

The key environmental principles and policy objectives to be achieved by installations using BAT are set out in Appendix 1 of the 1992 Convention for the Protection of the Marine Environment of the North East Atlantic ("the OSPAR Convention") and also in the European Community Directive 96/61/EC on Integrated Pollution Prevention and Control ("the IPPC Directive").

It is suggested that the broad environmental principles that guide the use of BAT could be:

- the use of low-waste technology;
- the efficient use of resources;
- the prevention and reduction of the environmental impact of emissions; and
- the use of less hazardous substances.

The concentration and containment of radioactive emissions is a central objective of BAT because "*the introduction of radioactivity into the environment is undesirable, even at levels where radiation doses to both human and non-human species are low and unlikely to cause significant harm*".[16] Furthermore "*the principle of progressive reduction is a central tenet of the way in which radioactive discharges should be controlled*".[17] The presumption under BAT is to prevent adding radioactive emissions into the environment where this can reasonably be avoided or to minimise the level of emissions where they cannot be prevented. Although BAT techniques for different types of nuclear installation are not defined in OSPAR, the IPPC Directive provides a clearer insight into what environmental protection strategies may generally be regarded as BAT. Integrated Pollution Prevention and Control (IPPC) is a system of environmental regulation which is currently being implemented throughout the European Community. Whereas in the past different environmental effects were often separately regulated, IPPC applies an integrated approach so that emissions of chemicals into the atmosphere or into rivers, steams and sewers or landfills must be considered jointly to minimise their overall impact upon the environment. IPPC applies to approximately 5 000 major industrial sites in the EC such as large chemical works, oil refineries, fossil fuelled power stations and waste incinerators. IPPC sets common standards for the control of emissions from industrial plants across the European Community. The standards which must be achieved are published in BAT reference documents (BREFs) which take account of the best available techniques for the abatement of specific types of pollution from specific industrial sectors. Hence the system of reference documents provides a level playing field of recognised environmental performance standards across the EC.[18]

Although radioactive emissions from nuclear installations are not regulated under IPPC, the approach to be taken in determining BAT for a nuclear installation will usually be a combination of compliance with general BAT principles together with an installation specific BAT assessment taking account of local environmental circumstances. Situations commonly arise where there is a need to balance trade-offs between reducing one pollutant and generation of other environmental impacts such as increased solid waste or greater energy use. The selection of a management technique or technology

16. *UK Strategy for Radioactive Discharges 2001-2020*. Defra. July 2002. ISBN 0 85521 013 3.

17. *Statutory Guidance on the Regulation of Radioactive Discharges into the Environment from Nuclear Licensed Sites – A Consultation Paper*. DETR (now Defra). October 2000.

18. See http://europa.eu.int/comm/environment/ippc/

option on the basis of too limited an examination can have the effect that environmental damage is not reduced, but displaced to another waste form or environmental medium or abatement process or geographic location. Such multi-media assessment is especially important for determining BAT for releases from nuclear installations because the management of substances which persist in the environment, such as radioactive emissions, is always likely to result in some form of displacement.

The essence of BAT is that operators should chose the best option available to achieve a high level of protection of the environment taken as a whole. However because the environmental impact of nuclear techniques is not narrowly confined to radioactive emissions and radiation doses alone, strategies to achieve BAT must consider a wide range of environmental factors. Fifteen optimisation factors for nuclear installations are identified in Figure 4 which underpin the four key BAT policy objectives in OSPAR and IPPC. Release practices from nuclear installations which take into account several or many of these factors are likely to be BAT whereas release practices from nuclear plants which take into account only a few or none of the factors are probably not BAT. The factors have been developed in a form that allows discretion about their methods of implementation without undermining their effectiveness. A general framework for consideration of the factors is discussed in subchapter (BAT decision-aiding methodology).

It is important to note that some of the factors compete with each other in opposing directions. For example the need to concentrate and contain radioactivity compared with the need to minimise stored radioactive wastes. Ultimately a judgement will be needed by the decision maker about which factors are of most importance in the specific circumstances of the nuclear installation being considered.

Figure 4a. **Nuclear BAT management factors for optimisation of releases from nuclear installations**

Use of low waste technology	Efficient use of resources	Reduced emissions	Use of less hazardous substances
• Minimise the generation of radioactive wastes from the nuclear facility	• Improve the eco-efficiency of the nuclear facility (e.g. emissions / Gwa)	• Concentrate and contain environmentally persistent or bioaccumulative emissions	• Radioactive wastes should be created in a passively safe waste form
• Radioactive wastes should be created in a manageable waste form	• Optimise both radioactive and non-radioactive impacts to reduce the environmental footprint of the facility	• Reduce transboundary geographic displacement of environmental impacts	• Condition and immobilise unstable waste forms into a passively safe state
• Minimise treatment and conditioning necessary to safely store wastes	• Prioritise environmental expenditure to maximise the amount of radioactive pollution avoided for each € invested	• Minimise potential radioactive releases from credible accident conditions and their consequences for the environment	• Wastes should be capable of interim safe storage prior to final disposal in a repository
	• Progressively reduce worker doses from waste treatment and conditioning processes	• Progressively reduce emissions	• Wastes should be capable of being stored in a monitorable and retrievable waste form

Figure 4b. **Nuclear BAT management factors for optimisation of releases from nuclear installations**

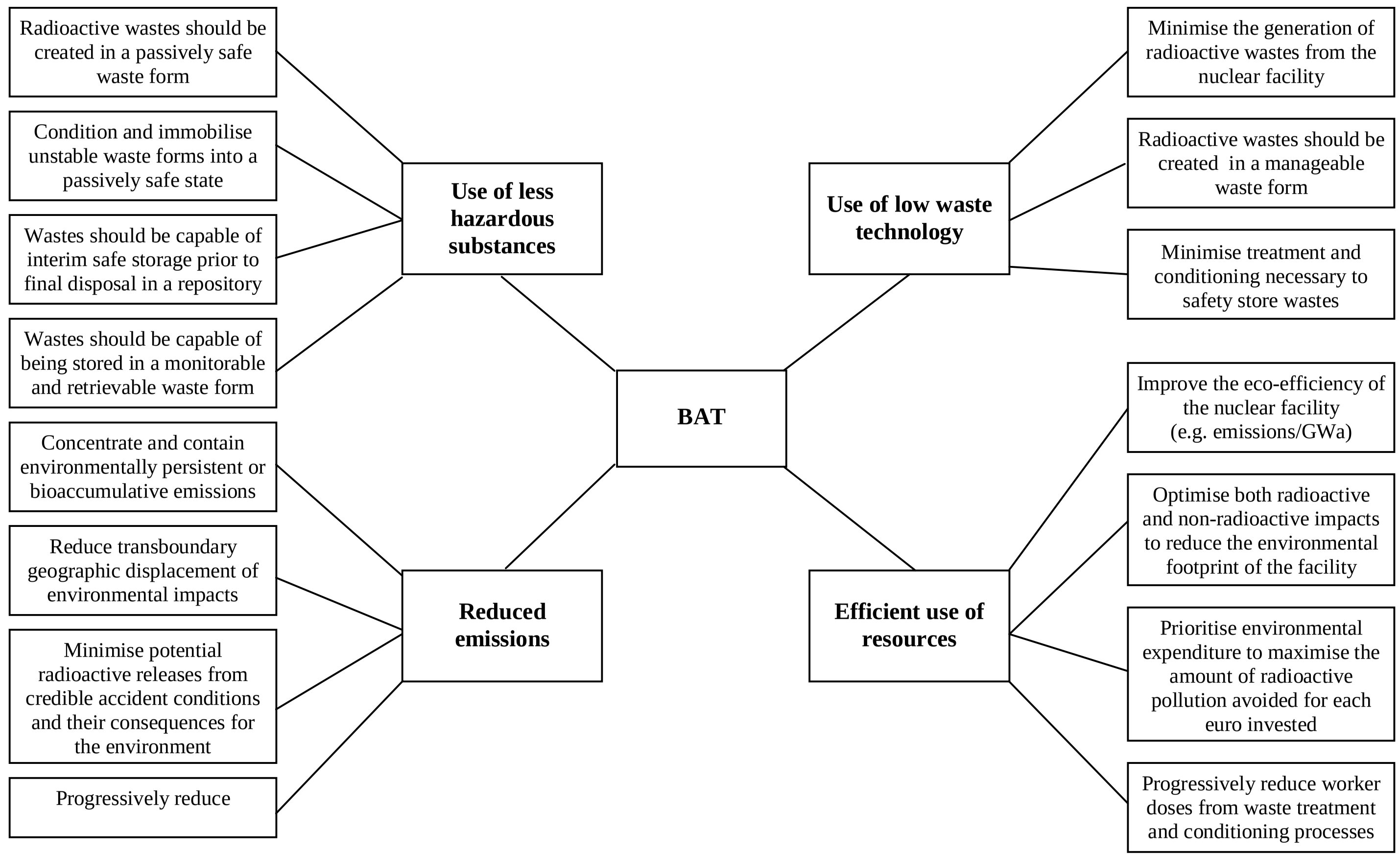
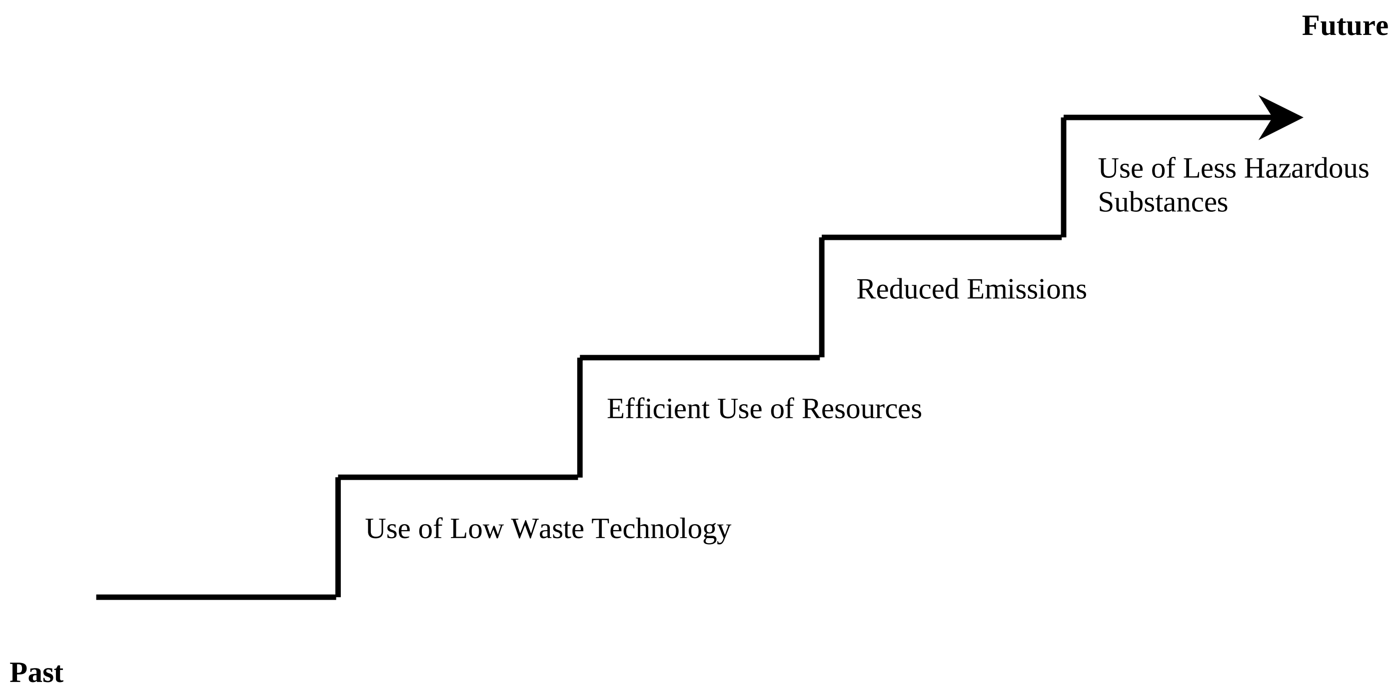


Figure 4c. **Environmental outcomes achieved using BAT**



Use of low-waste technology

Environmental protection strategies for nuclear installations require the performance of the waste producing processes to be properly optimised rather than simply accept the generation of solid radioactive wastes as an intrinsic by-product of plant operation.

The optimisation of plant processes to "design-out" solid, liquid and gaseous waste by-products is important because end-of pipe emission abatement systems often generate solid wastes such as HEPA filters, filter beds and ion exchange resins which are difficult to condition into a passively safe form. Immobilisation of the waste into a passive form is important to minimise the need for maintenance, monitoring or other human interventions which themselves create further secondary wastes.

The nuclear BAT factors given in Figure 4 are intended to support clean technologies by optimising processes to eliminate solid waste production through reduction of waste at source, or where some creation of waste cannot be avoided, to ensure that waste volumes are minimised and can be safely disposed.

For installations producing plutonium, uranium and fission product, a high level of protection of the environment can be achieved through the implementation of process optimisation and abatement. BAT for less radiotoxic nuclides such as carbon-14 and tritium or technetium-99, which are difficult to abate and have a lower environmental impact, might be to dilute and disperse the effluent waste streams into the receiving environment. However, before deciding upon the final choice of optimisation the BAT decision must take care to account for stakeholder views which matter to people as well as safety and environmental protection criteria.

Efficient use of resources

Although the main focus of environmental management decisions will be upon the direct impacts of radioactive emissions and radioactive waste, BAT management factors should also take into account the indirect environmental impacts of the technology chosen for optimisation of releases. The broad aim is to reduce the overall environmental impact of the process with BAT options that use fewer resources such as energy consumption, water consumption and uranium raw material supply. Economic resources are also an important component of the evaluation of different BAT options especially where the long term effects of reducing discharges towards zero may result in increased costs for the conditioning, storage and disposal of solid radioactive wastes.

The nuclear BAT factors in Figure 4 are intended to help compare the efficiency of different release options using indicators of nuclear environmental performance and financial performance. Efficiency indicators are broad brush statistics which help to differentiate between options according to the amount of reduction in emissions they achieve.

A wide range of indicators can be used to help prioritise the expenditure of economic resources on different effluent management options and understand the environment benefits that they deliver. The boxes below show examples of indicators and their numeric values for PWR and Reprocessing plants.

Eco Efficiency Indicators for the Nuclear Industry*

Environmental Indicators		
	Volume of solid waste	(m^3 / GWa)
	Activity of solid waste	(Bq / GWa)
	Fuel consumption	(tU / GWa)
Safety Indicators		
	Dose to the public	(Sv / GWa)
Economic Indicators		
	Capital cost	(€ / GWa)
	Marginal operating cost	(€ / GWa)

* *Nuclear Energy in a Sustainable Development Perspective*, OECD/NEA 2000.

Examples for Gaseous Emissions from PWR Reactors and Reprocessing Installations*

PWR Reactor

^{3}H	840	GBq / GWa
^{14}C	200	GBq / GWa
^{85}Kr	6	GBq / GWa

Reprocessing Installation

^{3}H	1 700	GBq / GWa
^{14}C	380	GBq / GWa
^{85}Kr	6 600 000	GBq / GWa

* *Radiological Impacts of Spent Nuclear Fuel Management Options*, OECD/NEA 2000.

Reduced emissions

The concentration and containment of radioactive emissions is a central objective of BAT because the introduction of radioactivity into the environment is undesirable, even at levels where radiation doses to both human and non-human species are low and unlikely to cause significant harm. The presumption under BAT is to prevent adding radioactive emissions into the environment where this can reasonably be avoided or to minimise the level of emissions where they cannot be prevented. However, optimisation using BAT techniques must not significantly increase other risks to the environment from accidental failure of the technology which could potentially give rise to much larger releases or increase occupational risks to workers who must operate and maintain the technology.

A relatively new and important issue when deciding upon the choice of BAT technique is the likely transboundary impact of radioactive emissions on the environments of other countries or at vulnerable boundary locations between countries. Once discharged, some discharges can persist within the environment for long periods of time and under some conditions may accumulate in biota. Examples include bioconcentration of organically bound tritium observed in English flounder, and technetium-99 in Norwegian lobster. Plutonium has also accumulated within sediments in the Irish Sea. The persistence and accumulative behaviour of some radioactive emissions merit special attention when making effluent management decisions. Application of the BAT factors in Figure 4 will help to ensure that these factors are taken into account.

Less hazardous substances

Achieving a shift in process technology toward the creation of less hazardous waste forms is the most demanding objective of BAT but offers the greatest opportunity for pollution prevention. Approaches to discharge management and reduction using BAT techniques often concentrate and contain radioactivity into solid waste forms. However this will require the retention of radionuclides in solid wastes for long term waste management which need to be taken into account. Environmentally persistent radionuclides with long half lives that exist in a mobile chemical form may pose significant difficulties in the far future because they could eventually penetrate the containment of their waste repository and be released into the environment in an uncontrolled and possibly concentrated form. In addition the long term influence of climate change is hard to predict but might accelerate the timescales within which radioactive substances are released from repositories and expose future populations, especially for low level wastes disposed on or near the land surface. The likelihood of these effects taking place can be reduced by the conditioning and immobilisation of radioactive wastes into a form that is physically and chemically stable. But decisions to treat waste also need to have regard to the potential occupational exposure of workers both from operation of the waste treatment plant and also from long term storage of the solid wastes and residues which will be produced.

When making a decision upon the choice of abatement, application of the nuclear BAT factors in Figure 4 will help to ensure that any solid waste products arising from the effluent management technique will be intrinsically less hazardous and capable of being safely stored for long periods.

Radioactive Waste Storage Concepts*

Passively safe storage means the immobilisation of solid radioactive wastes into a form that is physically and chemically stable so that they may be stored in a manner which minimises the need for environmental control and safety systems, maintenance, monitoring and human intervention.

Interim safe storage means the safe containment and storage of a package of waste, possibly for several decades, before its final disposal in a repository.

The **disposability** of a waste package is the likelihood that a package of waste that has been conditioned into a physically and chemically stable form before a disposal site is available, will be acceptable for disposal to the future repository site.

* *Current Arrangements and Requirements for the Conditioning, Packaging and Storage of Intermediate Level Radioactive Waste*, Radioactive Waste Management Advisory Committee. DEFRA 2002.

BAT decision-aiding methodology

This subchapter explains the key managerial processes for aiding decisions on effluent release options and discusses practical emission abatement techniques that are available for nuclear installations. The available release option techniques will vary with the type of nuclear installation considered, such as a nuclear power plant, reprocessing facility, fuel fabrication plant, waste treatment and storage plant, research reactor or radiochemical laboratory, and will have different magnitudes of cost. Recognising that the primary environmental effect of different release options is unlikely to be represented by a single number, the nuclear BAT factors developed in this chapter provide a simple framework in which to aggregate on a common basis the environmental advantages of various emission control techniques being considered. BAT decisions are not taken in isolation but involve balancing a wide range of factors to help identify what combination of measures (process design, management, abatement) constitute BAT for releases from an installation. This approach avoids complex risk assessments to explore “how much damage is safe”, and concentrate instead upon "how little damage is possible".[19] Economic assessment of the available options is also critically important since environmental improvement is typically costly and extra costs are rarely attractive to those who have to pay them.

Annex 4 presents a simple methodology for decision aiding using indicative nuclear BAT factors. Case studies from Cogema and BNFL illustrate how these factors have been taken into account below.

Consultation with stakeholders is also important when selecting the best available techniques, because the simplifying effect of arithmetic can too easily disguise the importance of qualitative arguments which also matter to people. When consulting stakeholders a location-specific BAT assessment is needed to take account not only of the high level technical characteristics of the technique, but also the influences of geographic location and local environmental conditions. Future limits on the concentration of radioactivity permitted in the environment will also affect the choice of BAT technique, especially where policy objectives intend to achieve progressive and substantial reductions in emissions or limit the concentrations of radioactivity close-to-zero in the receiving environment.

Decision Making versus Decision Aiding*

Discussions within the radiological protection community, which mirror broader discussions of the much more general subject of modern governance, have converged on the idea that a better understanding of the roles of various stakeholders in the decision-making process would very much facilitate finding solutions that can be accepted. As part of the understanding of these roles a clear theoretical distinction is made between "Decision Making" and "Decision Aiding". Decision making is intended to mean the process of arriving at a decision that is accepted. Decision aiding is intended to mean the development of elements (technical, social, economic) that are necessary to make an informed decision.

* *The Way Forward in Radiological Protection*, OECD/NEA, Paris, 2002.

19. *Making Better Environmental Decisions: An Alternative to Risk Assessment* by Mary O'Brian. Massachusetts Institute of Technology. MIT Press. 2000. ISBN 0-262-15051-4.

Best Available Techniques Case Study
Optimisation of Reprocessing Activities at Cap de la Hague
Using Evaporation Technology

Cogema employs a combination of process waste recycling, evaporation and vitrification technologies to optimise effluent releases from its reprocessing facility at La Hague in France. Process effluents are collected, treated and recycled into the plant generating small amounts of solid waste which are immobilised by vitrification into a passively safe glass waste form that is suitable for transport, long term storage or disposal. Irradiated fuel is dissolved in the plant using highly concentrated nitric acid and its uranium content separated from fission products using an organic solvent extraction process. Waste nitric acid washings are passed through an evaporation cycle which removes fission product impurities and concentrates the acid washings for return into the dissolution process. A similar treatment process recycles waste organic solvent which is concentrated by distillation in an evaporator and returned to the solvent extraction process. The remaining solid wastes are vitrified apart from a small organic fraction which is conditioned using a calcination process and then grouted into a solid waste form.

Cogema developed new BAT evaporation technologies employed in its UP2-800 and UP3-A plants which substantially improved the decontamination factors (DFs) for medium and low activity effluents and as a consequence reduced emissions into the marine and air environment. The treatment of medium and low activity waste streams was optimised by separately treating acid and alkaline process effluents using dedicated evaporators to achieve higher DFs. The residual high activity concentrates occupy less volume and are also made passively safe by immobilising them in the waste vitrification plant. The introduction of BAT evaporation technology allowed both a reduction in high level waste volumes and also reduced emissions into the environment.

Best Available Techniques Case Study
Abatement of Carbon-14 Emissions from Reprocessing Activities at Sellafield Using Gas Scrubber Technology *

BNFL's thermal oxide reprocessing plant (THORP) at Sellafield in the UK prevents discharges of carbon-14 using gas scrubber abatement technology. Irradiated nuclear fuel contains carbon-14 resulting from activation of trace quantities of nitrogen-14, which is present as an impurity in uranium fuel rods. Carbon-14 is an environmentally important radionuclide because it is both persistent in the environment, having a half life of 5 730 years, and also easily metabolised by biota since it is biologically identical to natural carbon. Within THORP the majority of carbon-14 is released during the dissolution of irradiated fuel in nitric acid. Carbon-14 reacts with nitric acid to form carbon dioxide which is diverted into a dissolver off-gas waste stream. The dissolver off-gas is passed through acid recombination and iodine absorption columns before passing into a caustic scrubber which removes carbon dioxide converting it to sodium carbonate effluent. Carbon-14 is then precipitated from the carbonate effluent with barium nitrate. Barium carbonate precipitate is removed from the effluent and conditioned by the Sellafield Encapsulation Plant (WEP) as an intermediate level waste for long term storage.

* *Using Life Cycle Assessment to Inform the Nuclear Debate,* Nuclear Energy. Volume 41. Number 6. December 2002.

Best Available Techniques Case Study
International Developments in Technologies for Abatement of Krypton-85 from Reactors and Reprocessing Plants*

The noble gases krypton-85 and argon-41 are released in gaseous emissions from both nuclear reactors and nuclear reprocessing plants. In reactors argon-41 is produced by activation of argon-40 which is naturally present in the air and found as a contaminant in cooling water. Krypton-85 is produced as a fission product in irradiated nuclear fuel. Argon-41 is not environmentally persistent, having a half life of 1.8 hours, but krypton-85 is more environmentally significant with a half life of 10.7 years. Both krypton and argon are released from reactors during refuelling outages, for example 6.1 GBq of krypton-85 per GWa from a typical PWR. Much larger quantities of krypton-85 are released during the reprocessing of irradiated fuel, typically 6.6 million GBq per GWa.

Although neither krypton nor argon are presently abated from emissions a recent international review conducted for the UK Environment Agency, concluded that low temperature cryogenic separation is technically and economically feasible. A cryogenic pilot plant has operated at both Tokai Mura in Japan and Idaho Falls in the USA for some years, although the technology costs have prevented its wider adoption. However, recent developments in the market demand for xenon gas for high intensity vehicle lighting applications has changed the balance of economics to favour cryogenic abatement from which xenon is a highly valuable by-product.

* Technical Feasibility Study of the Cryogenic Separation of Xenon from Reprocessing Plant Off-Gases. Sellafield Authorisation Review. Environment Agency, 2002.

9. CONCLUSIONS

The outcome of this NEA work is seen as a contribution to national and international discussions in this area, and should assist the development of national approaches to effluent release management. Regarding the review of the current system of radiological protection, which includes the review of the concept of optimisation as one of the basic principles of radiological protection, it is hoped that this report will provide useful technical background for further discussions on the optimisation of effluent releases.

Historically, application of ALARA has helped to protect man from the health effects of ionising radiations and, as a consequence, has also achieved significant reductions in the total quantities of radioactivity discharged into the environment from nuclear installations. However, following the 1992 Rio Earth Summit, many countries have incorporated the concept of BAT into their national environmental protection legislation, reflecting a shift in emphasis towards sustainable development. While ALARA will continue to be important in the future for protection of the public from exposure to radioactivity, protection of the environment seems to be shifting towards a BAT approach which is becoming the central mechanism by which waste producing processes are optimised at nuclear installations. Although BAT and ALARA already share much common ground, the factors which influence BAT are different and much wider than ALARA's health protection focus. A framework of practical guidance is needed to achieve BAT.

In summary, the nuclear industry continues to operate within existing national frameworks and international recommendations, and will support change as national and international requirements and recommendations evolve. Effluent releases from nuclear installations, during normal operations, are well below current national regulatory requirements, and have been optimised through the implementation of the ALARA principle. In order to support informed decisions on that evolution of national and international policy, this report provides the reader with the implications of incorporating BAT as an additional tool in further reducing effluent releases.

Annex 1

MEMBERS OF THE EXPERT GROUP ON THE IMPLICATIONS OF EFFLUENT RELEASE OPTIONS

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Annex 2

TERMS OF REFERENCE (AS APPROVED DURING THE FIRST EGRO MEETING AND BY THE CRPPH BUREAU)

Background

Radioactive effluent releases from nuclear installations, in normal operation, have been reduced in recent years and are still subject to discussions. The demand for further reductions is generally driven by societal concerns about the protection of the environment. Regarding the optimisation of effluent releases, there are several different approaches. The chemical industry, for example, introduced the concept of the "best available technology (BAT)", while the radiation protection system uses the ALARA approach. The OSPAR Commission, a political body concerned with the pollution of the marine environment, introduced a strategy with regard to radioactive substances which calls for a reduction of radioactive emissions to a level that would result in concentrations of artificial radionuclides in the environment that are "close to zero".

At its 59th meeting, held on 5-7 March 2001, the NEA Committee on Radiation Protection and Public Health (CRPPH) agreed to launch an Expert Group to discuss and investigate the implications of effluent release options. The Committee asked the Secretariat to draft terms of reference for such a group. The CRPPH Bureau reviewed and approved the terms of reference by correspondence, and CRPPH nominated expert group members.

Terms of Reference

The Expert Group approved the following Terms of Reference:

1. Identify various options for the routine release of low-level radioactive substances from nuclear installations, including the option of "close to zero" gaseous and liquid releases.
2. Discuss the technical implications of the options identified.
3. Compare the concepts of "best available technology (BAT)" and "as low as reasonable achievable (ALARA)" as underlying principles for the optimisation process regarding radioactive effluent releases. Investigate whether these approaches lead to the same result.
4. Based on this work, develop a draft document presenting factual information on various effluent release options, in co-operation with other NEA committees such as the CNRA, NDC and RWMC. The document may be used to assist future discussions, nationally and internationally. Submit the draft document to CRPPH members for review and comment, with the aim of publication by the end of 2002.

Annex 3

GENERIC DISCHARGES FROM A PWR AND A REPROCESSING PLANT

Information given in this Annex is taken from the NEA publication *Radiological Impacts of Spent Nuclear Fuel Management Options* (OECD/NEA, 2000).

Reference power generation facility and generic discharges

Annual discharges from a typical 1 300 MW(e) PWR were derived on the basis of French data (Deprés, 1999) and are given in Table 1. On the basis of available information, it was assumed that there was no significant difference between discharges from a reactor loaded with UO_2 and one loaded with MOX.

Reference reprocessing facility and generic discharges

The La Hague 1997 liquid and gaseous discharges (Cogema, 1998a, b) have been normalised to 1 GWa to define the generic releases given in Table 2. Normalisation was made with a burnup of 30 GWd/tHM, as suggested by the original data, rather than with the 40 GWd/tHM adopted generally for this study. It is assumed that this should not affect the final results, as a higher burnup would imply more energy extracted from the fuel but also a higher inventory of radioactive nuclides.

The data include the releases from such activities associated with the reprocessing plant as conditioning of uranium and plutonium to oxides, and treatment and conditioning waste, as well as from storage of spent fuel, separated uranium, and waste on the reprocessing site.

Table 1. **Generic annual discharges from a PWR**

Radio-nuclide	Annual discharges (GBq/a)		Normalised annual discharges* (GBq/GWa)	
	Gaseous	Liquid	Gaseous	Liquid
^{3}H	9.0×10^{2}	1.8×10^{4}	8.4×10^{2}	1.6×10^{4}
^{14}C	2.2×10^{2}	1.6×10^{1}	2.0×10^{2}	1.5×10^{1}
^{41}Ar	3.5×10^{1}	Not discharged	3.3×10^{1}	Not discharged
^{54}Mn	Not discharged	1.5×10^{-2}	Not discharged	1.4×10^{-2}
^{58}Co	1.7×10^{-4}	3.7×10^{-1}	1.6×10^{-4}	3.4×10^{-1}
^{60}Co	6.5×10^{-6}	1.7×10^{-1}	6.1×10^{-6}	1.5×10^{-1}
^{63}Ni	Not discharged	$4.0\ 10^{-1}$	Not discharged	3.7×10^{-1}
^{85}Kr	6.5	Not discharged	6.1	Not discharged
^{88}Kr	2.3×10^{-1}	Not discharged	2.2×10^{-1}	Not discharged
$^{110}Ag^{m}$	Not discharged	9.5×10^{-2}	Not discharged	8.9×10^{-2}
^{124}Sb	Not discharged	5.0×10^{-2}	Not discharged	4.7×10^{-2}
^{131}I	1.6×10^{-2}	1.5×10^{-2}	1.5×10^{-2}	1.4×10^{-2}
^{133}I	2.0×10^{-3}	Not discharged	1.9×10^{-3}	Not discharged
^{133}Xe	5.0	Not discharged	4.7	Not discharged
^{134}Cs	Not discharged	6.0×10^{-2}	Not discharged	5.6×10^{-2}
^{137}Cs	Not discharged	1.8×10^{-1}	Not discharged	1.6×10^{-1}

* An electricity generation of 1.07 GWa was taken in normalising the discharges.

Table 2. **Generic discharges from a reprocessing plant**

Radionuclide	Annual activity released (GBq/GWa)	
	Liquid	**Gaseous**
^{3}H	2.6×10^{5}	1.7×10^{3}
^{14}C	2.1×10^{2}	3.8×10^{2}
^{54}Mn	1.1	
^{57}Co	3.0×10^{-2}	
^{58}Co	3.6×10^{-1}	
^{60}Co	1.1×10^{1}	
^{63}Ni	2.9	
^{65}Zn	3.7×10^{-2}	
^{85}Kr		6.6×10^{6}
^{89}Sr	8.2×10^{-1}	
$^{90}Sr/Y$	8.2×10^{1}	
$^{95}Zr/Nb$	8.7×10^{-3}	
^{99}Tc	2.9	
$^{106}Ru/Rh$	4.3×10^{2}	7.2×10^{-4}
^{125}Sb	3.0×10^{1}	
^{129}I	3.6×10^{1}	3.7×10^{-1}
^{131}I*		2.6×10^{-2}
^{133}I*		6.9×10^{-3}
^{134}Cs	4.6	
^{137}Cs	5.4×10^{1}	1.3×10^{-6}
$^{144}Ce/Pr$	6.5×10^{-2}	
^{154}Eu	9.0×10^{-2}	
U	1.4×10^{-1}	
^{238}Pu	2.1×10^{-1}	1.7×10^{-7}
$^{239/240}Pu$	1.1×10^{-1}	1.3×10^{-7}
^{241}Pu	4.6	
^{241}Am	1.3×10^{-1}	
^{244}Cm	5.4×10^{-2}	

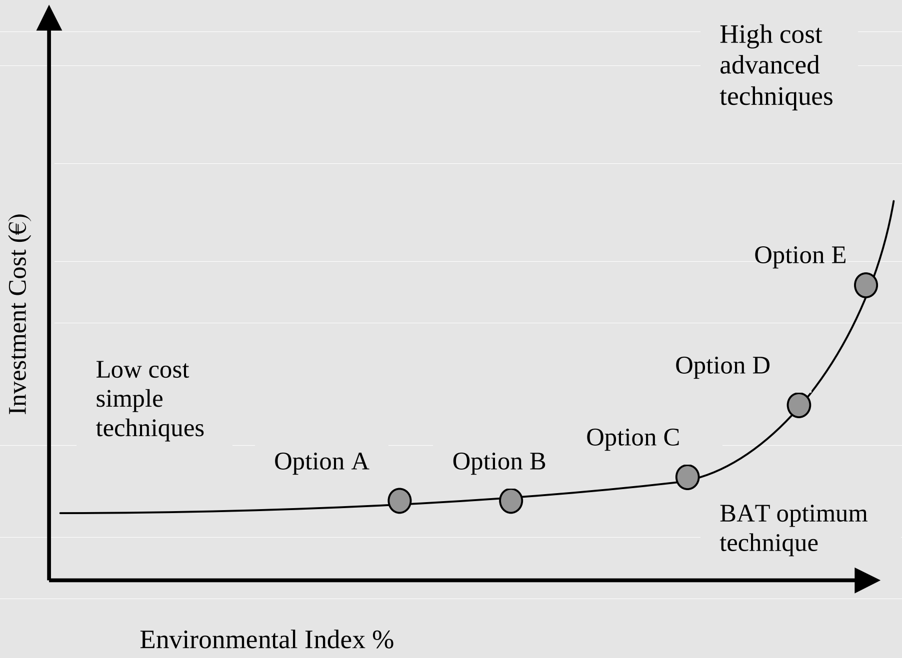
* These radionuclides come from the spontaneous fission of curium.

Annex 4

EXAMPLE FOR A BAT DECISION-AIDING METHODOLOGY

Based on the discussion in Chapter 8, Figures 5 and 6 show a simple methodology for decision aiding using indicative nuclear BAT factors. The factors in Figure 5 have been organised into a management checklist which may be applied to each of the effluent management techniques being considered. The Environmental Index (%) of each technique is calculated by determining the number of factors (N) that will be achieved by the technique compared with the maximum number of BAT factors. The total costs of each technique option (capital build cost, lifetime operational cost and decommissioning cost) must also be assessed. When several options are considered together it is possible to identify the point at which the cost of improving the Environmental Index increases significantly in disproportion to other options (see Option C and Option D in the box below) which represent the most likely BAT techniques. It is unlikely that a single environmentally optimum technology will clearly be the most cost-effective choice and in practice two techniques, with different combinations of environmental impacts, may need to be discussed with stakeholders before deciding upon the overall best release option.

Selection of Best Available Technique (BAT)*



* Adapted from IPPC Environmental Assessment and Appraisal of BAT.
IPPC H1 Horizontal Guidance Note. Environment Agency. 2002.

Figure 5. **Example for an environmental index checklist[20] for assessing release options from a nuclear installation**

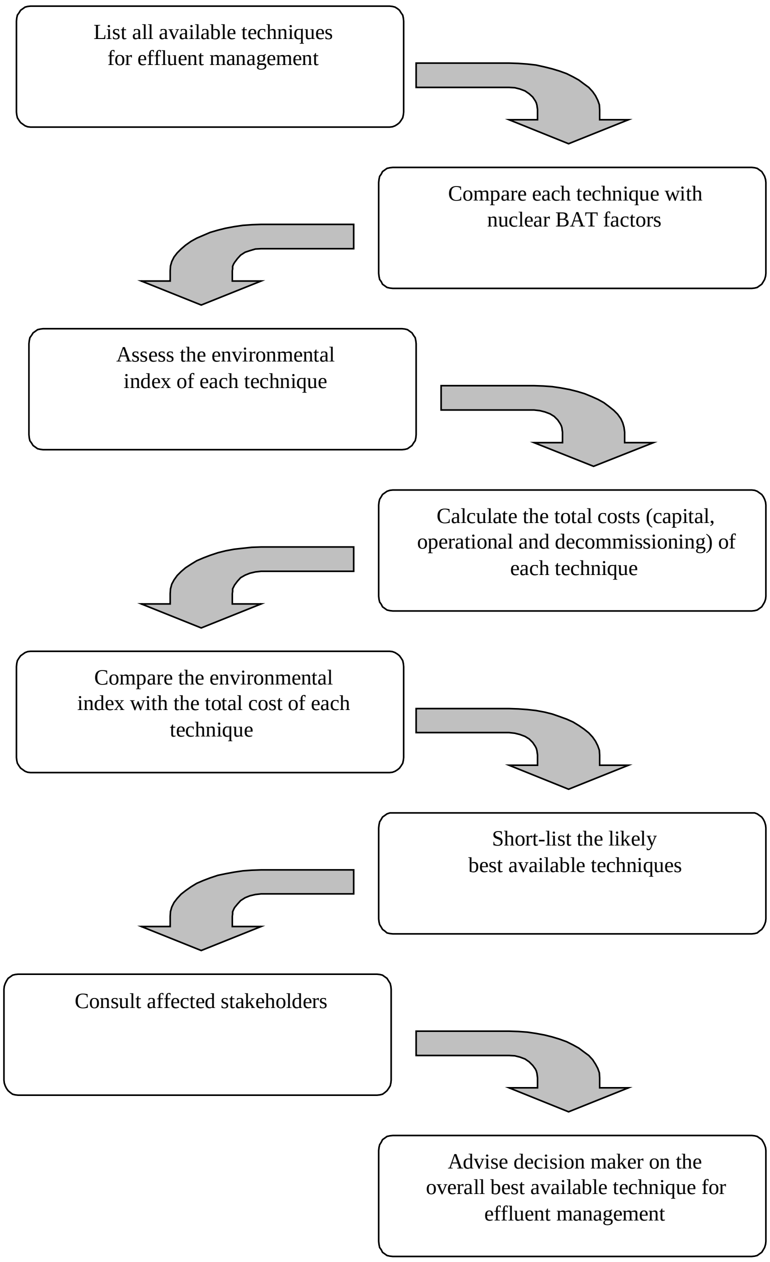
BAT Environmental Outcome	Nuclear BAT Management Factor
Less hazardous substances	• Progressively reduce worker doses from waste treatment and conditioning processes
	• Wastes should be capable of being stored in a monitorable and retrievable waste form
	• Wastes should be capable of interim safe storage prior to final disposal in a repository
	• Condition and immobilise unstable waste forms into a passively safe state
	• Radioactive wastes should be created in a passively safe waste form
Reduced emissions	• Progressively reduce doses to the public from radioactive facility emissions
	• Minimise potential radioactive releases from credible accident conditions and their consequences for the environment
	• Reduce transboundary geographic displacement of environmental impacts
	• Concentrate and contain environmentally persistent or bioaccumulative emissions
Efficient use of resources	• Prioritise environmental expenditure to maximise the amount of pollution avoided for each € invested
	• Jointly optimise both radioactive and non-radioactive impacts to reduce the environmental footprint of the facility
	• Improve the eco-efficiency of the nuclear facility (emissions / GWa)
Low solid waste technology	• Minimise treatment and conditioning necessary to safely store wastes
	• Radioactive wastes should be created in a disposable waste form
	• Minimise the creation of radioactive wastes from the nuclear facility

Number of factors achieved	(N)
Environmental Index	(%)

Environmental Index (%) = Number of Factors Achieved by the Technique (N) ÷Total Number of BAT Factors (15) x 100

20. Adapted from *Integration of Business Strategy In Establishing Significant Environment Aspects* by Enrico Cagno and Paolo Trucco, Politecnico di Milano, Italy. Greenleaf Publishing. 2000. ISBN 1874719276.

Figure 6. **Example of a decision-aiding process for selecting the BAT effluent release option**



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Effluent Release Options from Nuclear Installations

Radioactive effluent releases from nuclear installations have generally been substantially reduced in recent years, well below regulatory requirements. At the same time, international and intergovernmental agreements and declarations, as well as national policies, continue to seek to optimise and further reduce such releases. Nevertheless, due to societal concerns about levels of radioactivity in the environment, the management of effluent releases from nuclear installations remains high on the agenda of public discussion.

This report provides basic technical information on different options for managing and regulating radioactive effluent releases from nuclear installations during normal operation. It should contribute to national and international discussions in this area and be of particular interest to both nuclear regulatory authorities and nuclear power plant operators.

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