UK EPR	Title: PCER – Chapter 8 – Best Available Techniques
	UKEPR-0003-080 Issue 04

Total number of pages: 131	Page No.: I / III
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REVISION HISTORY

Issue	Description	Date
00	First issue.	28-06-08
01	PCER March 2010 update Relevant references marked as CCI Complementary information included in - sub-chapter 8.1 section 1 - sub-chapter 8.2 sections 2.3, 3.3.1, 3.3.1.1.1, 3.3.1.1.5, 3.3.1.2.1.2, 3.3.3.1, 3.3.3.2 and Table 1 - sub-chapter 8.3 section 3.1 Minor editorial changes	28-03-10
02	PCER March 2011 update - Minor editorial corrections - §8.1: Remove CCI for the documents BAT and IWS - §8.2: Section 3.3.1.2.1.2 and 2.1: information added regarding choice of materials and primary coolant chemistry and zinc injection. - §8.2 Sections 3.3.3.1, 3.3.3.2: information added regarding assessment for the filtration and demineralisation systems of the CSTS, LWPS and SGBS systems. - §8.4: complementary information added	30-03-11
	Protect Commercial marking removed	
03	PCER Reformatted Version - Minor formatting changes and editorial corrections - References listed under each numbered section or sub-section heading numbered [Ref-1], [Ref-2], [Ref-3], etc	09-01-12

Continued on next page

REVISION HISTORY (Cont'd)

Issue	Description	Date
04	Consolidated PCER update: - Minor editorial changes in o Sub-chapter 8.1 section 1, o Sub-chapter 8.2 sections 2.3, 3.1, 3.2.2, 3.3, 3.3.1.2.1.1, 3.3.1.2.1.4, 3.3.1.3, 3.3.3.5, 3.3.4, 3.4, 3.4.6, 4.1.2 and 4.1.4.2 o Sub-chapter 8.3 section 2.2 o Sub-chapter 8.4 sections 1, 3.2 and 5.1 - Minor editorial and typographical changes for consistency / clarification in Sub-chapter 8.2 sections 3.2.2, 3.2.2.1, 3.3.1.2.1.3, 3.3.1.3, 3.3.2, 3.3.3, 3.3.3.1, 3.3.3.2, 3.3.3.3, 3.3.4, 3.4, 3.4.1, 3.4.2, 4.2.1.4, Table 1, and Figure 1 and in Sub-chapter 8.4 sections 2.3.2, 2.3.3, 3.2 and Table 8 - Update for modification related to gamma spectrometry devices for measuring noble gases (in Sub-chapter 8.4 section 2.3.4) - Updates to reactor chemistry aspects and cross-references to Sub-chapter 5.5 added for consistency (Sub-chapter 8.2 §3.2.2, §3.3.1, §3.3.1.1.1, §3.3.1.1.4, §3.3.1.1.5, §3.3.1.2, §3.3.1.2.1.1, §3.3.1.2.1.2, §3.3.1.2.1.3, §3.3.1.2.2, §3.3.1.2.3, §3.3.1.3, §3.3.3.3, §3.4) - Update of references and replaced French references with English references in Sub-chapter 8.2 - Clarification on incineration of LLW in Sub-chapter 8.2 section 3.2.2.1 - Consistency with PCER Chapter 2 in Sub-chapter 8.3 sections 1.1 and 1.2	28-08-12

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CONTENTS CHAPTER 8

SUB-CHAPTER 8.1 – INTRODUCTION

LIST OF FIGURES

1. SCOPE AND OBJECTIVE OF THE CHAPTER

As part of the Generic Design Assessment (GDA) of candidate nuclear power plant designs, the Environment Agency (EA), in the Process and Information (P&I) Document [Ref-1] requires that the requesting parties provide an evaluation of options considered in the design of the Nuclear Power Plant (NPP) and undertake an assessment of emissions from their proposed plan in accordance with the EA's guidance note, Integrated Pollution Prevention and Control (IPPC) Environmental Assessment and Appraisal of Best Available Techniques (BAT). Specifically, this chapter deals with the EA requirements of the P&I Document [Ref-1] regarding the concept of BAT, i.e. requirements:

- 1.5: *"an analysis should be provided that includes an evaluation of options considered and shows that the Best Available Techniques will be used to minimise the production and discharge or disposal of waste."* In particular, this should consider issues relating to:
  - Waste generating and management process: description of the methods implemented to minimise waste arising and discharged or disposed of, along with a demonstration that they are the best available;
  - Minimisation of arisings and disposal of waste during operation of the reactor: review of the design features; and
  - Forward planning and minimisation of the waste arising from decommissioning activities: review of the features of the particular design candidate.
- 2.6: Methods of determination of discharges by demonstrating that the techniques and systems proposed for measurement and assessment of discharges and disposal of radioactive waste represent the best practicable means for such analyses; and
- 3.2: Arising, management and disposal of liquid waste streams, providing a demonstration that BAT and good practices are used to prevent direct or indirect discharges to groundwater, prevent or minimise emissions of pollutants from each significant effluent stream along with consideration of the means of control in the event of detection of unplanned radioactive or other contamination of the discharge.

The objective of this chapter is to provide an evaluation of environmental options considered and to show that the BAT have been used to minimise the production and discharge and disposal of waste. Aspects related to the decommissioning strategy and the treatment strategy for radioactive waste have been reviewed in Chapter 5 of the PCER.

In order to meet this objective, this chapter describes successively the following points:

- Sub-chapter 8.2: Design process of EPR:
  - historical background;
  - environmental approach; and
  - description of optimisation measures (for each significant stream: solid waste, liquid and gaseous radioactive discharges, chemicals, etc.) assessed with regard to the BAT management factors set out below and EA requirements.

- Sub-chapter 8.3: Application of BAT standards and good practices for the design of the EPR;
- Sub-chapter 8.4: Implementation of BAT within monitoring procedures.

It is concluded that processes implemented or proposed to be implemented in the EPR are compliant with the BAT requirements as set out by the Regulators and ensure that, considering the current techniques available, EDF and AREVA will not have to implement any further reasonable practicable improvements. The documents ‘BAT Demonstration’ [Ref-2] and ‘Integrated Waste Strategy’ [Ref-3] provide more details.

2. THE CONCEPT OF ‘BEST AVAILABLE TECHNIQUES’ (BAT)

The European Union (EU) has established a set of common rules for industrial installations and defined the concept of BAT in the Integrated Pollution Prevention and Control (IPPC) Directive of 1996 [Ref-1]. The Pollution Prevention and Control Act 1999 (PPC Act [Ref-2]) received Royal Assent in 1999 and implements the requirements of the 1996 EU Directive on Integrated Pollution Prevention and Control (IPPC).

IPPC requires competent authorities to ensure that *“installations are operated in such a way that all the appropriate preventative measures are taken against pollution, in particular through the application of Best Available Techniques …”*. This concerns, in essence, minimising pollution from various point sources throughout the EU.

The definition of BAT in IPPC has been incorporated into the Pollution Prevention and Control Regulations (PPC Regulations, [Ref-3]), of which there are separate statutory instruments for England, Wales and Scotland. In these documents, **‘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”*.

Further clarity on BAT is provided within Regulation 3 of the PPC Regulations [Ref-3] as follows:

- “Techniques” shall include both the technology used and the way the installation is designed, built, maintained, operated and decommissioned;
- “Available” techniques shall mean those developed on a scale which allows them to be used in the relevant industrial sector, under economically and technically viable conditions, taking into consideration the costs and advantages;
- “Best” shall mean most effective in achieving a high general level of protection of the environment as a whole.

The point of the IPPC Directive [Ref-1] 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.

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.

In addition to the above definitions, Schedule 2 of the PPC Regulations describes special considerations to be taken into account in the determination of BAT as follows:

- the use of low waste technology;
- the use of less hazardous substances;
- the furthering of recovery and recycling of substances generated and used in the process and of waste, where appropriate;
- comparable processes facilities or methods of operation which have been tried with success of an industrial scale;
- technological advances and changes in scientific knowledge and understanding;
- the nature, effects and volume of the emissions concerned;
- the commissioning date for new or existing installations;
- the length of time needed to introduce the best available technique;
- the consumption and nature of raw materials including water, used in the process and the energy efficiency of the process;
- the need to prevent or reduce the impact of emissions on the environment and the rise to it;
- the need to prevent accidents and to minimise the consequences for the environment; and
- the information published by the Commission pursuant Article 16(2) of the Directive or by international organisations.

Note: The Environmental Permitting Regulations came into force in April 2008 and replace the PPC permitting regulations along with a range of other regulations.

The role of the Office for Regulation (ONR)

The ONR expects the safety cases for all nuclear facilities to include a demonstration that the rate of production and accumulation of waste has been reduced so far as is reasonably practicable. This should include an optimisation study of the activity in liquid and gaseous routine discharges, solid waste arisings, occupational exposure and environmental impact. Although each regulator will make its decisions on matters for which it is responsible, well-developed arrangements exist to ensure that they properly co-ordinate their activities. These arrangements include Memoranda of Understanding agreed by the relevant regulators. In particular, the EA is concerned not only with ‘end of pipe discharges’ and BAT applied to these but also to the minimisation of waste at source (on the site), an area where the ONR will also have a regulatory interest.

3. OVERVIEW OF UK REQUIREMENTS AND EA GUIDANCE

This section reviews and presents some of the key concepts from the Environment Agency.

The regulation of radioactive waste discharges and disposals is governed by two optimisation concepts that have been part of UK pollution law for many years and which, taken together with the ongoing pressure for review and improvement underlying their application, are considered to be at least equivalent to BAT. These concepts are Best Practicable Environmental Options (BPEO) and Best Practicable Means (BPM).

The concept of BAT is essentially the same as BPM and/or BPEO, and therefore it is generally admitted that it delivers the same level of environmental protection.

For information, in an EA guidance to be published soon, the approach to determining BAT is described as including:

- An options identification and appraisal, including cost-benefit analysis where appropriate;
- The adoption and implementation of the EA guidance where this sets out indicative BAT requirements; and
- The adoption and implementation of good practices, as set out in codes of practice and standards.

Meanwhile, the IPPC H1 Guidance Note [Ref-1] gives detail on how to assist Applicants in responding to the requirements described in the IPPC Sector and General Guidance Notes (non-radioactive substances). As stated in this guidance, BAT may be demonstrated by either:

- Demonstrating compliance with the relevant ‘BAT standards’ listed in the sector specific guidance notes; or
- By conducting an installation specific options appraisal of candidate techniques (to minimise impact on the environment).

The later option is usually carried out when:

- More than one candidate for BAT exists for the prevention or minimisation of a particular pollutant or pollutants;

- An operator proposes to deviate from the indicative BAT standards; and
- No indicative BAT standard is available.

As NPPs are not specifically regulated by PPC (only auxiliary and directly associated processes can be regulated by PPC), there are no sector specific BAT standards for the actual NPP to compare against. Nevertheless, a small number of auxiliary plants and processes can be subject to regulation under PPC, and therefore some sector specific BAT standards may be applicable for these, provided that they are not inconsistent with safety specifications of NPPs.

More generally, as no BAT standard is available for the overall NPP, an options appraisal should be undertaken. The methodology described to undertake a full BAT assessment is similar to the methodology usually in place to carry out a BPM and/or BPEO assessment [Ref-2].

In addition, it is important that this assessment takes account of the requirements of relevant guidance and good practices, and of the local environmental context in which the facility will operate. Indeed, local factors such as population and sensitivity of environmental receptors are of major importance when it comes to determining whether additional or different techniques are required.

New facilities are normally expected to comply with or go beyond any existing indicative standards. However, the Government and Regulators accept that this may not be possible in some circumstances due to site-specific factors. In that case, the operators may propose an improvement plan to the regulators. This improvement plan will describe a range of measures which will be aimed at achieving BAT within a pre-agreed timeframe (e.g. 3 to 5 years).

Once a BAT has been identified, the Regulators will be expecting it to be implemented in the facility on a day-to-day basis. Normally, what represents BAT may change with time both as a result of technological developments and in the light of policy, regulatory and societal changes. As such, in the case of existing and significant plant and processes, the Agencies would normally expect the operator to ensure that BAT continues to be applied. This may require an appropriate improvement or optimisation programme to be implemented to ensure that discharges are progressively reduced. Therefore, the operator is required to ensure that processes, techniques, procedures or management systems that constitute BAT are periodically reviewed.

Finally, the implementation of a BAT assessment will help the EA to set discharge limits at the minimum necessary levels to permit ‘normal’ operation or decommissioning of a facility.

The UK Strategy for Radioactive Discharges [Ref-3] also requires observance of the Precautionary Principle, the Polluter Pays Principle and a proportionate approach. It is UK Government policy that *“the unnecessary introduction of radioactivity into the environment is undesirable, even at levels where the doses to both humans and non-human species are low and, on the basis of current knowledge unlikely to cause harm”*. Furthermore *“the principle of progressive reduction is a central tenet of the way in which radioactive discharges should be controlled”*. 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.

Together, these concepts, and the way in which they are incorporated within the process of authorisation review, place a continuous pressure for improvement on operators, which is consistent with the objectives of BAT.

4. DECISION MAKING STRATEGIES FOR DISCHARGES AND SOLID WASTE OPTIONS

Under PPC, techniques for BAT for various sectors are available in the UK in the form of sector specific BREF Notes. Nuclear installations do not fall under this particular regulatory regime and for this reason, equivalent sector specific guidance on what constitutes BAT is not available. Instead, BAT analyses are made on a case-by-case basis. The EA has published information on what it sees as processes likely to constitute BAT and extensive information on how it expects operators to demonstrate BAT.

Note: As mentioned before, some plants on nuclear sites such as certain boilers, diesel sets, waste incinerator, non radiological hazardous waste storage, non radiological non hazardous waste management, or some processes such as chlorination of water or cleaning or regeneration of charcoal and ion exchange resins used in water treatment processes however do fall under PPC. In the framework of GDA, the diesel generators have been identified as such (see Chapter 3 of the PCER).

In order to give an example of how the concept of BAT could apply within the nuclear sector, the Organisation for Economic Co-operation and Development (OECD) has developed a decision-aiding strategy for effluent discharges optimisation based on factors indicating the application of ‘best available techniques’ [Ref-1].

Nuclear BAT management factors

The key environmental principles and policy objectives to be achieved by installations using BAT are set out in the IPPC Directive [Ref-2].

It is suggested that the four key environmental principles that guide the use of BAT are:

- 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.

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 and safety aspects. 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. This process of optimisation is not restricted to the consideration of radioactive substances and their resulting doses but must also have regards to safety considerations, security, wider environmental considerations and social and economic considerations.

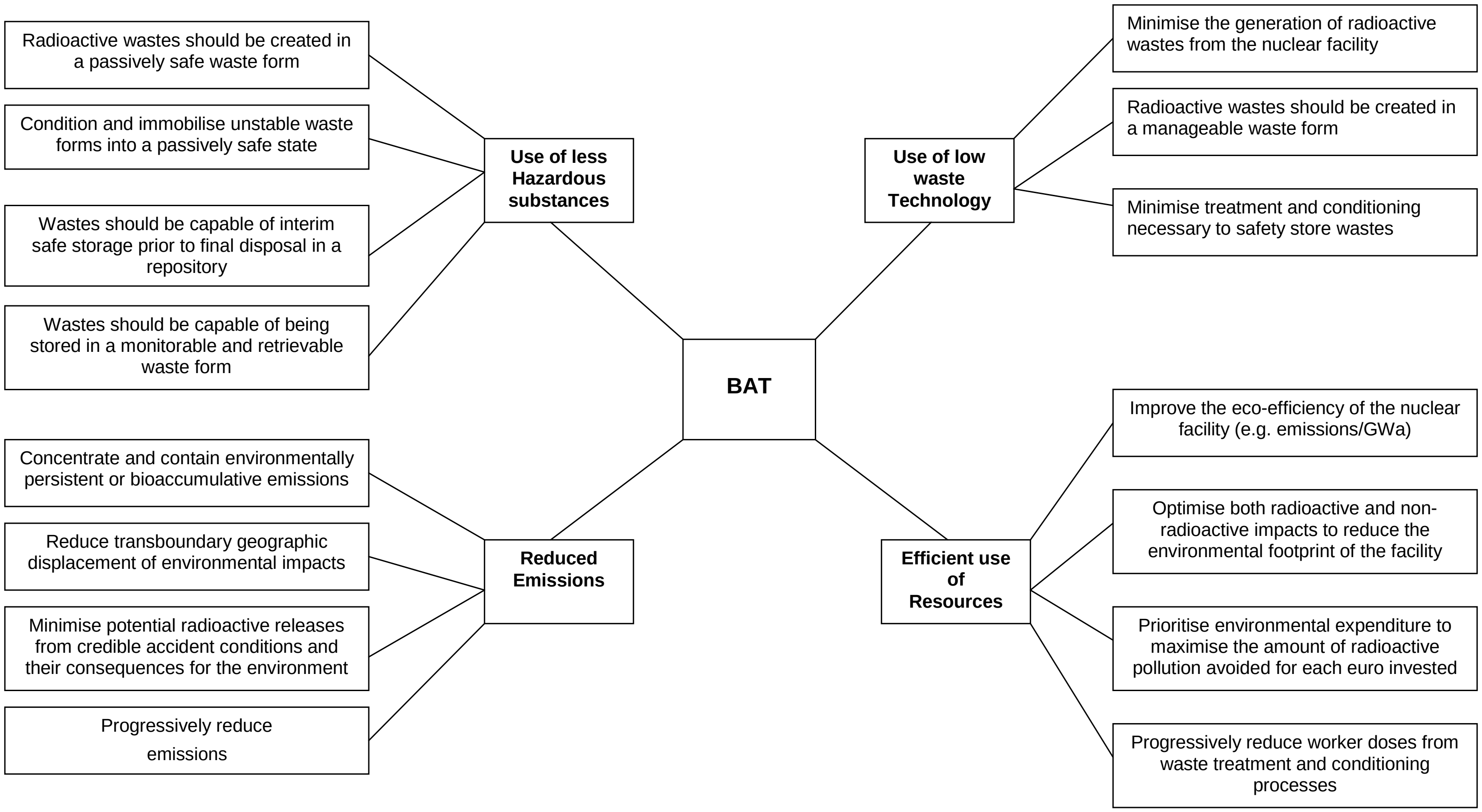
The selection of a management technique or technology option not based on a rigorous examination can have the effect that environmental damage is not reduced. Instead, impacts will be displaced to another waste form, environmental medium, abatement process or geographic location. Such multi-media assessment is especially important for determining BAT for discharges from nuclear installations because the management of substances which persist in the environment, such as radioactive emissions, is likely to result in some form of displacement.

The essence of BAT is that operators should choose 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 Sub-chapter 8.1 - Figure 1 underpinning the four key BAT policy objectives described above (use of low waste technology, efficient use of resources, reduced emissions and use of less hazardous substances) and in IPPC [Ref-2].

Discharge practices from nuclear installations which take into account several or many of these factors are likely to be BAT whereas discharge practices from nuclear plants which take into account only a few or none of the factors are probably not BAT.

The various techniques described in the following sub-chapters will be assessed with regard to the fifteen optimisation factors identified for nuclear installations in the OECD report [Ref-1]. It is understood that not all discharge practices will answer all of the optimisation factors, but that compliance to several of these will enable one to assume that the practice is BAT.

Sub-chapter 8.1 - Figure 1: Nuclear BAT management factors [Ref-1]



SUB-CHAPTER 8.1 – REFERENCES

External references are identified within this sub-chapter by the text [Ref-1], [Ref-2], etc at the appropriate point within the sub-chapter. These references are listed here under the heading of the section or sub-section in which they are quoted.

1. SCOPE AND OBJECTIVE OF THE CHAPTER

[Ref-1] Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs. The Environment Agency. January 2007. (E)

[Ref-2] GDA UK EPR – BAT Demonstration. UKEPR-0011-001 Issue 06. EDF/AREVA. August 2012. (E)

[Ref-3] GDA UK EPR – Integrated Waste Strategy. UKEPR-0010-001 Issue 03. EDF/AREVA. June 2012. (E)

2. THE CONCEPT OF ‘BEST AVAILABLE TECHNIQUES’ (BAT)

[Ref-1] European Community Directive 96/61/EC. Integrated Pollution Prevention and Control. 1996. (E)

[Ref-2] The Pollution Prevention and Control Act 1999 (as amended). HM Stationery Office. August 1999. ISBN 0105424994. (E)

[Ref-3] Pollution Prevention and Control Regulations 2000. SI No. 1973. The Stationery Office Ltd. ISBN 978-011099621-9. (E)

3. OVERVIEW OF UK REQUIREMENTS AND EA GUIDANCE

[Ref-1] Integrated Pollution Prevention and Control (IPPC) – Environmental Assessment and Appraisal of BAT. Horizontal Guidance Note IPPC H1. Environment Agency & Environment and Heritage Service & Scottish Environment Protection Agency. July 2003. (E)

[Ref-2] Guidance for the Environment Agencies’ Assessment of Best Practicable Environmental Options Studies at Nuclear Sites. Environment Agency and Scottish Environment Protection Agency. February 2004. (E)

[Ref-3] UK Strategy for Radioactive Discharges 2001-2020. DEFRA. July 2002. (E)

4. DECISION MAKING STRATEGIES FOR DISCHARGES AND SOLID WASTE OPTIONS

[Ref-1] Effluent release options from nuclear installations. Technical background and regulatory aspects. OECD 2003. (E)

[Ref-2] European Community Directive 96/61/EC Integrated Pollution Prevention and Control. 1996. (E)

SUB-CHAPTER 8.1 - FIGURE1: NUCLEAR BAT MANAGEMENT FACTORS

[Ref-1] Effluent release options from nuclear installations. Technical background and regulatory aspects. OECD. 2003. (E)

SUB-CHAPTER 8.2 – DESIGN PROCESS OF EPR

LIST OF TABLES

LIST OF FIGURES

The information presented in this sub-chapter is in direct response to requirement 1.5 on Best Available Techniques (BAT) demonstration of the Environment Agency (EA) Process and Information (P&I) Document [Ref-1].

1. CHOICE OF NUCLEAR POWER

The Government has published two recent papers relating to the future of electricity generation in the UK.

The White Paper on Energy [Ref-1] states that the development of the renewable energy and carbon capture and storage for fossil fuel fired power plants, as well as using nuclear energy may enable the United Kingdom to make real progress now towards tackling climate change and ensuring secure and affordable energy supplies. The second paper was published to consult on the future role of nuclear energy [Ref-2]. In this paper it is stated that *“the Government believes that new nuclear power stations could make a significant contribution to tackling climate change. We recognise that nuclear power alone cannot tackle climate change, but....it could make an important contribution as part of a balanced energy policy.”*

Following the public consultation carried out by the Government in 2007, a White Paper on Nuclear Power was published in January 2008 [Ref-3]. This stated that: *“…the Government has today concluded that nuclear should have a role to play in the generation of electricity, alongside other low carbon technologies. We have therefore decided that the electricity industry should, from now on, be allowed to build and operate new nuclear power stations*”. Indeed, in order to achieve the target of reduction of carbon dioxide emissions by 60% by 2050 set by the Government, it is evident that *“nuclear power has a key role to play as part of the UK’s energy mix”*.

In this context, Nuclear Power is considered as one of the BAT to produce electricity with minimal impact on the climate and on the environment. Indeed, nuclear power is widely recognised as a low-carbon emission technology. Some assessments have shown that the greenhouse gases emission factor of nuclear power is around 5 g CO_2-equiv. per kWh(e) when considering the full cradle-to-grave cycle [Ref-4] compared to up to 30 g CO_2-equiv. per kWh(e) for hydropower, around 5 g CO_2-equiv. per kWh(e) for wind power and up to 1200 g CO_2-equiv. per kWh(e) for power produced from fossil fuels.

2. EPR: AN EVOLUTIONARY DESIGN

The construction and operation of an industrial establishment requires that their effects be limited via measures in a wide variety of fields. Continuous efforts are devoted to reducing the impact of nuclear installations on the aquatic and terrestrial ecosystems.

These efforts and the consequent level of controls exercised relating to nuclear safety, radiological protection and the environmental protection result in a strong commitment to preserving the environment.

The need to optimise effluent management has been an integral part in developing nuclear facilities and this ‘optimisation principle’ was inherent at the earliest design stage of such facilities. In particular, the effluent treatment systems implemented and their ability to recycle the effluents demonstrate the commitment to this principle.

Several designs of Nuclear Power Plants (NPPs) are commercially available, and being envisaged in the UK. All the features present on the EPR have been developed using operation feedback from the very wide experience of EDF and AREVA, along with some other more recently developed techniques. In particular, attention has been given to reducing the production of waste and the liquid and gaseous discharges, along with reducing as far as possible the doses to the worker, public and the environment incurred by the nuclear activities.

Since the 1980s, French activities have been focused on further reducing the discharges of radioactive effluent to a level ‘as low as reasonably practicable’ (ALARP), as recommended by international and intergovernmental organisations such as Organisation for Economic Co-operation and Development (OECD) and International Atomic Energy Agency (IAEA). In particular, a number of recommendations from the Electric Power Research Institute (EPRI) have been considered, such as:

- improvement of collection and effluent treatment systems; and
- implementation of a robust effluent management system.

As a consequence, the volume of effluent produced and therefore discharged by the French NPP in the environment has been significantly reduced and a 100-fold reduction of the radioactive liquid effluents discharges has been achieved over the last 24 years.

2.1. HISTORICAL BACKGROUND

Context of requirements integrated by the EPR

The Franco-German Pressurised Water Reactor (PWR) project has been characterised by ambitious objectives in terms of nuclear safety and economic performance. Radioactive discharges under normal operating conditions have been subject to the setting of initial expectations and the specification of safety requirements by the French and German nuclear safety authorities:

- objectives and expectations associated with general safety objectives regarding operating conditions (personnel and public exposure) as of 1993 [Ref-1]:
    - “*minimise personnel dose exposure and radioactive releases and waste during normal operation*“;
- Technical Guidelines adopted in October 2000 [Ref-2] :
    - “*…limit… public exposure to radioactive releases in air or water…*”
    - “*… further reduce the activity and volume of materials to be discharged as waste*”
    - “*actions employed to minimise releases must be assessed against the quantities of waste resulting from the implementation of these actions*”.

These objectives are to be based on an optimisation and experience feedback process applied to the following areas: specification of materials, primary coolant chemistry, reduction of corrosion deposits, treatment of liquid and gaseous radioactive effluents and solid radioactive waste:

- objectives stated in French Nuclear Regulatory Agency (ASN) letters [Ref-3] with emphasis on radioactive discharges and waste activity:
    - *"…ensure that the Preliminary Safety Report presents quantitative objectives regarding the reduction of the activity and volume of radioactive waste and effluents within the scope of a global optimisation process … and … describe the measures adopted to achieve these objectives";*
    - *"Another objective, based on operating experience feedback, is to take into account operating constraints since the design stage … so as to limit radioactive releases and the quantity and activity of the waste produced".*
- These requirements, guidelines and objectives were in addition endorsed by EDF and converted into commitments in 1999 and 2000.

In addition to the objectives described above, the EPR must comply with the more general regulations for nuclear installations and the protection of the environment. In particular, these regulations aim to reduce the impact of discharges and nuisances incurred by industrial activities and, therefore, protect both populations and the environment.

The experience and feedback from the existing fleet of NPPs has been integrated and built on in the EPR design. Starting points for optimising the environmental options of the EPR were therefore the following:

- strong willingness to benefit from all the lessons learnt in the past; and
- 1300 reactor-years of operating experience of French and German PWRs.

The two main aims were:

- to limit the radiological impact on the public during normal operation, notably by reducing liquid and gaseous discharges and solid wastes (see sections 3 and 4); and
- to reduce the radiological consequences in case of incidents/accidents (see Chapters 14 and 16 of the PCSR).

2.2. FRENCH LEGISLATIVE BACKGROUND

In France, the 'Decree 95-540 of 4 May 1995' and the 'Order of 26 November 1999' set out technical directions concerning the discharge limits and method of sampling discharges released by nuclear installations.

Furthermore, the amended 'order of 31 December 1999' prescribing the general technical regulations (RTGE) aims to prevent and limit the harmful effects and external risks resulting from operating the nuclear facilities.

The ‘order of 26 November 1999’ states, in Article 8 for gaseous discharges and in Article 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 consequential 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*”.

One of the main applicable laws is also the French Act n°2006-686 of 13 June 2006: “Loi n°2006-686 du 13 juin 2006 relative à la transparence et à la sécurité en matière nucléaire”.

A summary of the French regulatory regime is given in Sub-chapter 3.8 of the PCSR.

The implementation of BAT in terms of the IPPC is thus clearly transcribed in French national legislation and thus applied within NPP design and operation.

It should be noted that the French National regulation 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.

2.3. INTERFACES OF THE DESIGN WITH THE ENVIRONMENT

The principle of BAT has thus been applied to the EPR unit during the design of the installation and is expressed in a systematic search for:

- Limitation at source of potential pollutants in the selection of the materials comprising the circuits and the packaging reagents;
- Even higher efficiency of the recycling and effluent processing systems (the selection of an advanced selective sorting system for liquid effluent and high-performance filtration, demineralisation, evaporation and storage processes);
- Design providing significant reduction of gaseous radioactive discharges (Gaseous Waste Processing System (TEG [GWPS]), ventilation and/or filtering systems, etc.);
- Technical solutions minimising the environmental impact regarding the cooling water intake and thermal releases;
- Limitation of freshwater use in the selection of the demineralised water production process;
- Proven design of fuel elements with similar specific power rate in order to prevent the risk of increasing fuel rod defects with contamination of primary coolant; and
- Optimised design to facilitate decommissioning.

The general and non-exhaustive list below provides an idea of the range of studies which were carried out:

- **Radioactivity:** identification and quantification of the different radionuclides, sorting and processing of effluent, conditioning of waste, radioecological surveys;

- **Water:** limitation of intake, better distribution of emissions, thermal, hydrological and hydroecological surveys;
- **Air:** better distribution of discharges, setup of measuring stations, meteorological surveys, distribution tests;
- **Noise:** limitation of noise and soundproofing (covers, silencers), simulation of sound impact;
- **Ecosystems (marine and continental):** physicochemical, biological, thermal and radioecological monitoring; and
- **Aesthetics:** architectural and landscaping surveys.

The integration of the environmental issues has been considered at several levels in the organisation of the EPR project:

- EDF R&D teams and other environmental specialist services such as CIDEN have been involved throughout the project;
- Specific teams have been identified to elaborate the environmental objectives of the EPR; and
- Parts of the project with a strong environmental dimension, such as the writing of the authorisations for creation and submissions for discharges, have been managed in collaboration between specialist teams.

The assessment of the environmental performance of the EPR involved a number of steps described below:

- In October 2004 an ‘EPR Environment’ [Ref-1] design review took place. This review, helped by the work undertaken by the EDF Engineering Teams, set the main environmental goals of the project (objectives and recommendations).
- This review was prepared during the first half of 2004 by an EDF Engineering Teams working group, which preliminarily produced several summary documents on the various waste and discharges generated by the EPR (in particular, radioactive, chemical and thermal discharges) and on the specific design characteristics of the EPR;
- An action plan was agreed upon following the ‘EPR Environment’ design review. This plan essentially considered short or medium-term issues. It was especially designed to deal with technical options still to be decided on and to be the link between design and implementation studies. This plan included a 9-item recommendation list to be assessed for potential design changes along with a ‘road map’ of the studies to be carried out in order to potentially implement these changes. In particular, the issues considered were:
    - Reduction and control of tritium liquid discharges, especially by reducing the source term. Amongst other topics, this resulted in the study on the lithium chemistry and decision to implement low-lithium chemistry;

- Reduction and control of carbon-14 liquid discharges. In particular, studies on the nitrogen blanket in the EPR Chemical and Volume Control System (RCV [CVCS]) tank concluded that the increase in carbon-14 is not negligible but the N_2 blanket remains preferable compared to the H_2 blanket due to operating constraints linked to H_2;

- Reduction of discharges of other radionuclides. Optimisation of collection and recycling of the primary effluent is to be sought wherever possible and in particular the maximisation of collection and/or recycling of fluids when draining circuits and components for maintenance;

- The best boron recycling techniques have been implemented to improve the design of the Liquid Waste Processing System (TEU [LWPS]), the Coolant Storage and Treatment System (TEP [CSTS]); the ‘zero leaking concept’ has been implemented as much as possible for valves and pumps packing containing borated fluid and the segregation of fluids in the RPE [NVDS] has been improved;

- Optimisation of the water quality and reduction of its silica content. This issue is highly site specific and should include considerations such as implementation of a desalination plant which would induce a reduction of chemical discharges (such as chemicals used for the regeneration of the usual demineralisation units);

- Overall reduction of chemical discharges. This in particular concentrated on optimising systems related to hydrazine, phosphate and total nitrogen. It lead to implementation of the elimination of hydrazine notably prior to release from the T (Liquid Radwaste Monitoring and Discharge System (0KER [LRMDS])) tank and hydraulic seals on the secondary side component cooling water system (i.e. the Conventional Island closed cooling water system (SRI)) to reduce releases of phosphates;

- Study of the need (environmental, technical, operational and economic) to regenerate the Steam Generator Blowdown System (APG [SGBS]) resins depending on the chemical conditioning of the turbine (turbogenerator). In the case of morpholine or ethanolamine conditioning, replacement of resins is favoured, while in the case of ammonia high pH conditioning, regeneration is necessary;

- Optimisation of the water intake and discharge temperature increase and flowrate based on technical, economical and regulatory aspects. This point is highly site specific; and

- Reduction of solid waste will be possible by ensuring segregation of wastes as they are generated, mainly during maintenance operations in the nuclear buildings and in particular by the implementation of a ‘cleanliness/waste’ zoning inside the controlled areas.

- Between November 2004 and May 2005, a specific ‘task force’ was implemented, aiming to determine the EPR expected performances, on the basis of the recommendations of the review, the operating feedback from the 1300 MW(e) fleet, the technical options considered and BAT. The expected performances determined were subsequently checked and assessed by groups of experts both within and outside of the EDF Engineering Teams, during the first half of 2005.

In addition to the above, an ‘Environment Committee’ (Comité Environnement) [Ref-2] [Ref-3] [Ref-4] was formed in 2007, and is now responsible for ensuring that the site data for solid waste, liquid and gaseous effluents (both radioactive and chemical) are in line with the environmental performances used as a design basis. This Committee, constituted of experts, regularly meets and ensures that the commitments to the environment are respected during all phases of work, including during the detailed study and the implementation phases. This process is currently ongoing.

These plans, reviews and task force demonstrate of the strong consideration given to the EPR environmental performance. They have resulted in some design changes or evolutions from the existing French or German reactors focused on environmental or safety performance, to lead to the EPR design. In particular, it has been essential that BAT for effluent management have been implemented first at the design stage of the facilities, but also when considering the technologies to be used during the treatment of the effluents and wastes.

Efforts have thus been focused at the design stage on reducing the emission of effluents at the source. In addition to this, the mitigation measures for the treatment of the effluents (both liquid and gaseous) before discharge and the methods of storage and discharge have also been optimised (see section 3 of this sub-chapter) in the light of the best techniques currently available. By taking account of all these improvements of the EPR basic design, expected performances without contingency and expected maximum discharges have been determined for the EPR (see section 4 of this sub-chapter).

In addition to these design improvements, the management system, the implementation of good practices (see both in Sub-chapter 8.3) and the monitoring actions (see Sub-chapter 8.4) will ensure that the EPR, as a whole, will be operated using BAT.

3. DESCRIPTION OF MAJOR OPTIMISATION MEASURES

3.1. METHODOLOGY

As stated in the introduction of this chapter, the methodology implemented for the evaluation of options considered at the design stage by the EPR is focused upon on a holistic approach:

- Ambitious objectives in term of nuclear safety, radiation protection and environmental performance; and
- Step-by-step approach: working groups, “EPR environment” design review (2004), an action plan and task forces have taken place and have identified environmental performances and further feasible improvements.

All these various aspects of the methodology have allowed determination of, for each significant waste generated:

- Design features, the means and management processes to minimise waste arising and discharged; and
- Set expected performances and maximum discharges.

These elements are in accordance with EA requirement 1.5 which stipulate that *"an analysis should be provided that includes an evaluation of options considered and shows that the BAT will be used to minimise production and discharge or disposal of waste"*.

It can be underlined that:

- EDF and AREVA optimisation approach is consistent with and complies with the principle of BAT set out in the IPPC Directive;
- The environmental performance of the EPR focuses on the prevention, i.e., the reduction at source which is the best option to minimise waste and discharges; and
- The applied techniques within the effluent and waste treatment systems of the EPR correspond well with recent operating feedback and technologies (e.g. effluent treatment techniques).

3.2. SOLID RADIOACTIVE WASTE AND SPENT FUEL

3.2.1. Spent fuel

Reducing the production of waste (particularly so-called 'long-lived' waste) for a given energy output, is key to optimising the nuclear fuel cycle from an environmental standpoint. This applies whatever the ultimate choice for long term management of this type of waste.

This objective is integrated into the design and performance options chosen when planning the EPR.

Once it has been producing energy in the reactor for a period of 5 or 6 years, a fuel assembly is spent and must be removed.

As regards to its core design and its use of fuel, the EPR reactor presents a number of evolutions developed thanks to previous experience of existing reactors. It uses the same types of fuel, enriched uranium and plutonium, as they do, but features of its design and enhancements in fuel performance mean that the yield is better.

In particular, compared to existing plants, the EPR enables:

- Better overall use of the fuel material as a result of increased operating and safety margins and more efficient use of the neutrons produced. Hence, it follows that there is less use of nuclear material to produce the same amount of energy. It is thus possible to reduce both the consumption of natural uranium and the quantity of waste produced by irradiation, for the same amount of energy produced; and
- Increased burn-up and increased flexibility to implement various types of Mixed Oxide (MOX) or innovative fuels.

Improved fuel performance

Improving fuel performance is an ongoing process which is gradually benefiting all the reactors currently in operation.

Management options considered in the design phase of the EPR correspond to the optimum of what can be envisaged today using current fuel products, i.e. an average burn-up in discharged assemblies of 60 GWd per Te, which can be compared to the typical PWR average burn-up of 45 GWd per Te currently achieved.

‘High burn-up’ management methods, which optimise the use of the fuel, are facilitated by the EPR design and allow savings of approximately 7% of the natural uranium resources required compared to current fuel for a given amount of energy produced.

EPR design features

Three EPR design options directly contribute to reducing natural uranium consumption, and spent fuel production, to produce a given amount of energy:

- Adoption of a ‘large core’, comprised of 241 fuel assemblies, compared to the 205 elements of the N4 units, for comparable electrical output. The yields achieved have the following physical bases:
    - Reduction in neutron leakage due to the increased size of the core; and
    - Additional assemblies leading to a 9% reduction in the linear power density of the core at nominal power. This enables neutron poisoning due to xenon to be reduced and above all, a smaller fraction of the core to be refuelled, for a given burn-up and operating cycle length.

Overall, for the 18-months operating cycle, taken as the reference, the improvements linked to the adoption of the ‘large core’ with its smaller refuelling fraction requirement enable savings in natural uranium of the order of 7%.

Also, the additional margins of the ’large core’ enable so-called ‘low leakage’ loading patterns to be adopted, which contribute to better fuel use by the reduction of radial neutron leakage:

- The use of a solid steel reflector called the ‘heavy reflector’. The reduction in radial neutron leakage it generates, once again, leads to savings of 2 to 3% of natural uranium consumed for a given energy output;
- The improvement in the overall thermal efficiency, and in particular the enhanced turbine efficiency, contributes 5% to the reduction in the consumption of uranium.

The increased yield in overall fuel efficiency (natural uranium) in the EPR, in view of the expected fuel characteristics in the medium-term, thus reaches 22% for an equivalent energy generation.

3.2.2. Solid radioactive waste

Solid waste from the Nuclear Island and the Effluent Treatment Building (ETB) that results from normal operation is sent to the Solid Waste Treatment System (8TES [SWTS]), and is then conditioned for interim storage and sending off site to a final disposal location, directly or via a treatment plant for additional processing (such as incineration and melting).

It includes:

- spent resin from the demineralisers from the various nuclear systems;

- filters from the various nuclear systems;
- concentrates from the evaporator of the Liquid Waste Processing System (8TEU [LWPS]);
- sludges from sumps and tanks bottoms cleaning;
- high-concentration chemical effluents from decontamination operations; and
- sundry operational waste that could be contaminated (such as vinyl, paper, scrap metals, etc.).

The sources of solid waste volume reduction currently envisaged are as follows:

- Implementation of clean-waste zoning, enabling better segregation of the different types of waste at the places of their generation and the production of conventional waste from non-contaminating work in the restricted area. Segregation of different types of radioactive waste leads normally to more efficient waste packaging;
- Better control of source term in the choice of materials in contact with the primary coolant leading to a reduction in the production of corrosion products (a reduction in cobalt-60 activity in particular);
- Optimisation of the chemical conditioning of the primary coolant (see section 3.3.1.2), in particular by:
    - Maintaining a constant pH value in the primary coolant by optimised regulation of the lithium concentration;
    - Controlling the concentration of dissolved hydrogen in the primary coolant so as to reduce the oxygen content and limit radiolysis;
    - Better elimination of the dissolved oxygen during boron recycling, by evaporation and degassing, and recombination of the hydrogen in the gaseous effluent treatment system; and
    - The injection of zinc into the primary system to prevent the incorporation of cobalt in the oxides from zones outside the flux;
- Taking more credit for the selectivity of Nuclear Vent and Drain System (RPE [NVDS]) drainage streams which enables recycling;
- A design improvement of the purification filters on the RCV [CVCS] providing greater filter surface area than that of the 1300 MW(e) and N4 units (multi-cartridge baskets and not single cartridge); and
- Better segregation of waste in the Effluent Treatment Building with an installation including a compacting press and a shredder, planned from the design phase; hence limiting the volumes of packaged waste generated.

It should be noted that the volume of solid waste notably depends on the balance between environmental discharges and packaged waste generation in managing the installation and may therefore change according to the various effluent treatment methods.

A formal BAT for each significant waste stream is given below. The information given below is based on treatment and conditioning processes as presented in Chapter 6 of the PCER.

3.2.2.1. Process waste

- Active spent Ion Exchange Resins (IER):

  Active spent ion exchange resins are embedded in a polymer matrix (epoxy). Two mobile units (so called MERCURE 1 and MERCURE 2) are in operation for the conditioning. One of these mobile units comes every 3 or 4 years on a given NPP site and it is connected onto the chosen spent resins storage tank (part of the 8TES [SWTS]). Details are given in Chapter 6 of the PCER.

  Mobile machines currently in operation represent the third stage of development of this kind of conditioning.

  In the 1980's, EDF performed a German process (STEAG) with a mobile machine called COMET to embed resins in a vinyl ester/styrene matrix. In the 1990's, another quite similar process (DOW CHEMICAL) was performed with a mobile machine called PRECED/PEC.

  Epoxy matrices have been chosen for safety reasons (risk of fire) and for a greater IER incorporation rate (58%). In comparison to cement matrix, polymer matrices have been chosen because of their:

  - higher containment level, required for keeping the radioactivity in the waste container;
  - better resistance to ageing mainly due to their resistance to irradiation;
  - lower weight and volume (factor 4 on density following incorporation); and
  - better compatibility with ion exchange resins (homogeneity of the waste block, significant tolerance particularly for high content of free water).

  The mobile machines (MERCURE) have also benefited from a new design allowing optimisation of dose uptake and higher conditioning throughputs (3 packages during a shift of 8 hours).

  In conclusion, polymer matrices and more particularly epoxy matrix have been selected as BAT because of the excellent behaviour of the final package with respect to containment and ageing requirements. Nevertheless, if it is considered that the concrete container itself can assure the activity containment, a cement matrix could also be considered.

  In the UK a similar mobile plant using a polymer matrix is used for treating Intermediate Level Waste (ILW) ion exchange resins at the Magnox Power Station sites. A mobile plant is also likely to be used for the Advanced Gas-cooled Reactor (AGR) sites, although a decision on cement or polymer is yet to be reached. At the Sizewell B (SZB) PWR, a decision is still to be reached on what constitutes BAT for the ILW resins. However, this is still likely to use an encapsulation process but one specific to the SZB site (as it uses different resins to the AGRs).

- Water filters (> 2 mSv h^{-1})

  Water filters are withdrawn from operation on the basis of clogging and/or dose rate. They are removed from the circuits via a handling machine which provides biological protection. They are ‘laid’ into a concrete container pre-equipped with biological protections and placed in a shielded cell. Then filters are capped by mortar. Afterwards, the container is transferred out of the cell for subsequent sealing.

  From a BAT perspective, the cementation allows a compact solid block to be formed which prevents the dispersion of radioactive particles even in the event of a package’s failure. This goal is reached by using a mortar (cement and sand) with a sufficient mechanical strength (3000 psi) and hence a significant radioactivity containment property.

  Repository considerations demand the lack of water pockets in the package, in case of penetration of water inside the repository’s vaults and hence the packages. Consequently, a new BAT improvement is currently planned with the development of a more fluid mortar formula for use during the packages’ filling.

- Sludges

  Sludges are transferred by pump into a concrete container or a metallic drum (depending on their radioactivity levels) and then mixed with mortar (cement and sand) and as necessary the addition of slaked lime to inhibit the retarding effect of boron and zinc on the mixture hardness.

  From a BAT perspective similar comments to those outlined above for water filter packages apply here. In this case the package can be considered as homogeneous, as the cement and waste are mixed. The required mechanical strength is 1200 psi.

- Evaporator bottoms concentrates

  Spent borated effluents are concentrated by evaporation. For the French fleet Liquid Waste Treatment System (8TEU [LWPS]) evaporators, the main specified limit values are: boron concentration < 50 $g.kg^{-1}$ (or 50,000 ppm), total salinity < 300 g l^{-1} and chlorine < 250 $mg.kg^{-1}$.

  Initially evaporator bottoms concentrates were mixed with a mortar and slaked lime inside concrete containers but since 2001 they have been incinerated.

  In order to optimise their transportation with minimised risk of boron crystallisation during transport, and to deliver to incineration facility a liquid ready to be introduced in the secondary chamber of the furnace, concentration is reduced to 17 $g.kg^{-1}$ (or 17,000 ppm) (the mass activity is about 5 to 6 GBq/te). A specific 17 m^3 tank has been developed for their transportation to the incineration facility.

  Incineration is the best available technique for LLW evaporator bottom concentrates because it may be considered that no residue is produced by this process.

- Water filters and air filters (< 2 mSv h^{-1})

  Water filters, air filters (pre-filters, absolute filters, iodine traps) are dismantled (separation of metallic frames from other parts) or shredded and put inside metallic drums then shipped directly to the high pressure compactor.

  From a BAT perspective water filters (with plastic frames) could be incinerated and air filters, of which the average mass activities are about a few Bq g^{-1}, could be disposed of in the LLW repository.

- Steam generator blowdown ion exchange resins

  These very low level wastes (average mass activity < 10 Bq g^{-1}) are directly shipped to the LLW repository in big-bags of 1 m^3. A small part of them (when mass activity is above 100 Bq g^{-1}) could be incinerated.

  From a BAT perspective the minimisation of package volume to be disposed of could be achieved by mixing them with other wastes with greater voidage (pipes, rubbles).

3.2.2.2. Technological waste

- Dry Active Waste (DAW) (> 2 mSv h^{-1})

  These technological wastes are conditioned exactly like water filters in concrete containers.

- DAW (< 2 mSv h^{-1}) and liquids

  The burnable part of technological waste (80 weight % of the overall DAW) and liquids (oils, solvents, chemical cleaning solutions and decontamination solutions) are incinerated. The use of plastic drums is recommended for DAW (easier incineration processing and minimisation of residues in comparison with the use of metallic drums).

  The non burnable part of technological waste (insulators, rubbles, air filters) are compacted in metallic drums on site; then drums could be compacted a second time in high pressure compaction prior to being placed in the repository.

- Scraps and other metallic wastes (< 2 mSv h^{-1})

  Scraps are generally cut down to sizes accepted by the melting facility (inductive furnace with a capacity of 4 Te). Ingots produced are disposed of in accordance with UK waste policy. However the main goal is to recycle the materials. For instance, the melting facility is equipped with a centrifuge unit able to create cylinders for use as internal shielding in concrete packages.

  The incineration process (thermal treatments in general) represents BAT today. Several possibilities exist depending on the types of furnaces required and also their location (e.g. a small unit on a given site (50 kg h^{-1}) or a bigger centralised one serving a large network of NPPs; the Centraco incinerator in France has a capacity of 500 kg h^{-1}). The amount of incinerated concentrates depends on the quantities of burnable DAW incinerated at the same time and calorific power provided.

In summary, the solid radioactive waste treatment processes implement the following technologies:

- sorting;
- shredding;
- drying of solid waste;
- compaction and super-compaction;
- handling devices; and
- surface decontamination (fuel flasks).

These technologies present several advantages and features:

- high volume reduction;
- compact design;
- reliable constructions;
- low maintenance;
- easy and readily available to use; and
- high degree of automation.

Summary of BAT assessment – Solid Waste Treatment

The techniques for the reduction of solid waste (radioactive and non radioactive) described above meet several nuclear BAT factors of the OECD report [Ref-1], in particular:

- Use of low-waste technology:
    - The use of compaction and/or super compaction, the reduction of the production of corrosion products and the limitation of packaged waste generated in the Effluent Treatment Building enable the generation of radioactive wastes from the nuclear facility to be minimised;
    - The low maintenance, easy operation and high degree of automation of the solid waste treatment system enables the treatment and conditioning necessary to safety store wastes to be minimised; and
    - The implementation of clean waste zoning and of an optimised segregation of waste enables radioactive wastes to be created in a more manageable form.
- Efficient use of resources:
    - The use of compaction and/or super compaction, the reduction of the production of corrosion products in the production of waste improves the eco-efficiency of the nuclear facility (e.g. lower emissions per GW);
    - The reduction in the production of both radioactive and non radioactive waste helps in the optimisation of both radioactive and non radioactive impacts and to reduce the overall environmental footprint of the facility; and
    - The high degree of automation of the solid waste treatment system and the control of the primary coolant chemistry enables a progressive reduction in worker doses.
- Use of less hazardous substances:
    - The creation of waste in a dry state and the generation of stable and safe products implies that the waste is created in a largely passively safe form; potentially unstable raw wastes are conditioned and immobilised into a passively safe state;
    - Once in a passively safe state, conditioned wastes will be capable of interim safe storage prior to final disposal in a repository; and
    - Wastes will be capable of being stored in a monitorable and retrievable manner.

3.3. LIQUID DISCHARGES

The control of radioactive and chemical discharges consists of:

- reducing the production of effluents at source;

- designing optimum effluent treatment and sorting systems; and
- designing suitable storage systems for the site.

The objectives pursued involve concentrating the radioactivity contained in liquid effluents in the form of a low volume of solid waste and the diluted, monitored and controlled discharge of residual radioactivity in liquid form, in accordance with the relevant authorisations.

This approach and the processes implemented constitute the best available technique at acceptable cost for the management of liquid radioactive effluents and achieve a balance between the worker doses incurred in treatment and the public doses and other environmental impacts incurred by discharge. The various technical points are described in more detail below. The operations will be subject to the ISO 14001 requirements.

3.3.1. Reduction of effluents source term

The EPR incorporates design improvements that aim to reduce the production of liquid chemical and radioactive effluent at source, in particular:

- The choice of materials which result in the process generating radioactive elements (reducing stellites, for example, a source of cobalt which produces cobalt-60 (Co-60)) (see PCSR Sub-chapter 5.5);
- Minimisation of sources that could give rise to isotopes such as silver-110m (Ag-110m), antimony-124 (Sb-124), antimony-122 (Sb-122) in the coolant – for instance by reduction in the use of helicoflex seals in favour of graphite seals, greater use of rotor stops and bearings without antimony (see PCSR Sub-chapter 5.5);
- Reinforced leak tightness requirements for active parts (pumps and valves) and the recovery of primary coolant leaks. This is done by using:
    - bellows seals;
    - reduced number of welds;
    - double barriers made of a double ring joint with a blocked port between the two rings;
    - leak-off lines: a pipe is placed on the valve itself; the connection to the RPE [NVDS] network is then performed by means of a hose pipe; and
    - double packing pressure seals.
- Zinc injection implementation in order to reduce the general corrosion of primary circuit materials and consequently the source term likely to be activated and discharged (see PCSR Sub-chapter 5.5);
- Among options for various coolant pH control (co-ordinating boron and lithium), the choice of constant $pH_{300°C}$ has been achieved in any fuel cycle scenario. This pH regime ensures minimisation of corrosion and build up of ‘crud’ in the reactor core (wherein formation of activation products takes place) and control over the transport of the activated material out of the core and into other downstream systems (see PCSR Sub-chapter 5.5);

- Enhanced filtration devices in the coolant clean up system RCV [CVCS] for removal of active particulate materials prior to return of the treated coolant to the circuit or their direction into other down-line systems;

- Ion exchange systems in the coolant clean up system RCV [CVCS] for removal of dissolved active materials prior to return of the treated coolant to the circuit or their direction into other down-line systems;

- Best available demineralised water used for primary coolant make-up. This ensures integrity of all primary (and secondary) circuit structural components (e.g. avoidance of stress corrosion cracking) and avoids build up of silica deposits on fuel rods (that can allow formation of zeolithes). It also minimises requirements for let down of coolant from the primary circuit and other systems due to impurity levels rising above those given in the relevant reactor coolant specifications (such as silica, sulphate, chloride); and

- Other methods for improving coolant water quality are being investigated such as filters in the RCV [CVCS], Fuel Pool Purification System/Fuel Pool Cooling System (PTR [FPPS/FPCS]), TEP [CSTS] with low leachable impurities (mainly silica) (see PCSR Sub-chapter 5.5).

In addition, operational and management controls add to optimisation via the rigorous management of effluent. This minimises the volumes and activities of waste at source and controls and optimises treatment and decisions regarding their discharge. These management procedures are used at all stages of plant start-up, operation at power and unit shutdown and refuelling. The controls draw on best available practice gained at other PWR plants over 20 or more years of operational history.

It is important to note that the reduction of effluents source term is a major principle of the EPR design. This principle complies with the definition of BAT as described in the IPPC Directive [Ref-1].

The primary circuit radioactivity in UK EPR has been reduced So Far As Is Reasonably Practicable (SFAIRP) by control of the primary coolant chemistry based on optimised conditioning and limitation of impurities [Ref-2] (see PCSR Sub-chapter 5.5).

3.3.1.1. Choice of materials

In order to limit the source term of radioactive pollutants, particular care has been given during the conception stage of the EPR to the specification of all materials in contact with the primary effluent in the primary circuit [Ref-1]. In particular, reduction (or suppression) of the cobalt content and optimisation of the releases of nickel (neutron flux generates nickel (Ni) to become activated in cobalt-58 (Co-58)) in the materials of the primary circuit have been achieved. Other improvements have also been implemented in the connected systems, such as:

- reduction of stellites;

- reduction of the cobalt residual content of all materials and alloys; and

- modifications in the construction of the steam generators.

3.3.1.1.1. Reduction of stellites

Stellites are cobalt–based alloys with hard-facing characteristics. However, when a stellite-coated surface becomes worn out, particles are likely to detach from it and flow within the primary liquid towards the reactor core, where the cobalt content of the alloy becomes activated, producing highly-dosing cobalt-60 to further deposit as ‘hot spots’.

Stellites are currently principally used in PWRs in:

- taps and valves; and
- some parts of the internal core support structure and primary pumps.

In the design stage of the EPR, particular care was taken to exclude stellites from all taps and valves. As such, it is expected that no radioactive liquid will come into contact with any stellite-containing valves. Instead, stellites will be replaced by a cobalt-free material with similar mechanical characteristics, or, in some cases, by an adequate nickel base (see PCSR Sub-chapter 5.5).

Thanks to these improvements on taps and valves, an 8% reduction of the total dose is expected for the EPR.

With regard to the stellite-containing surfaces in the internal core support structures, optimisation measures are still currently being developed by EDF and AREVA. These surfaces will be reduced as much as possible in comparison to the current French PWRs and only surfaces with high mechanical-load will be coated with stellites. It is expected that this will lead to a 4% reduction of the total dose for the EPR.

In addition, work is currently ongoing by EDF and AREVA on all the stellite-containing parts of the reactor coolant pumps.

3.3.1.1.2. Reducing the cobalt content of materials and alloys

The cobalt-content of all materials will be optimised and consideration given to the manufacturing feasibility (i.e. manufacturing technological limits), costs incurred by high purity requirements and dosimetry performance.

3.3.1.1.3. Manufacturing of steam generator tubes

Constant improvements are being made in the construction of steam generator tubes in 690 Alloy, optimising the behaviour of the material against corrosion and release of particles.

It should be noted that 690 alloy was chosen instead of 800 alloy on stress-corrosion resistance and on overall steam-generator design. Recommendations aiming at optimising the behaviour of the 690 alloy in terms of dose uptake have been associated with this choice (see Chapter 12 of the PCSR).

3.3.1.1.4. Optimisation of the primary coolant chemistry conditioning during hot functional tests

Hot Functional Tests (HFTs) are carried out during phase III of the pre-operational test programme (Plant Commissioning Programme – see Chapter 19 of the PCSR). The contact of the primary circuit with water at high temperature produces the material corrosion and the formation of an oxide layer on primary circuit surfaces. The less general corrosion the lower source term will be and the more protective the layers, the less corrosion particles leakage will occur during cool-down periods. It is therefore generally recognised that the conditioning of hot functional tests is one of the factors having effect on the minimisation of the source term and contamination.

Several practices have been applied during HFT for optimising the general corrosion release and the passivation process via controlling the concentration of lithium, boron, oxygen and hydrogen and via the zinc injection application.

The overall implementation procedure of the Hot Functional Tests will be decided at the UK-EPR following an ALARP (As Low As reasonably Practicable) approach based on a balance between the expected benefits and the tolerable risks associated with safety, wastes and radioprotection considerations. The Operating Experience Feedback (OEF) from N4-EDF units, Sizewell B and Tomari 3 (with zinc injection) will also be taken into account as it suggests that a good passive film has been produced throughout the primary circuit, minimising corrosion product release.

In addition, it is expected that treatment of the primary fluid on filters and ion exchangers will incur an increased elimination of corrosion products. This purification step both before and during the surfaces' pre-oxidation step is therefore an important part of the optimisation process of the Hot Functioning Test for the EPR.

3.3.1.1.5. Potential improvement of steam generators channel heads by surface electro-polishing

It was estimated for the EPR, using operational feedback from 1300 MW(e) French units as well as other international data, that treating the steam generators channel heads by electro-polishing may reduce the equivalent doses by 40% in the zones treated. This would imply an improvement on the annual collective dose of around 10 man mSv, equivalent to an overall 3% decrease on the collective dose.

Electro-polishing of steam generator channel heads will be an operator specific choice and the assessment of the optimal arrangements for undertaking this during manufacture (type and length of treatment) will be chosen taking into account the cost and schedule.

3.3.1.2. EPR chemistry as a design parameter

See PCSR Sub-chapter 5.5.

An evolutionary approach to integrating chemistry into the EPR design has been adopted in consistency with an ALARP approach[1] mainly based on:

- Critical and objective examination of French, German and international operating feedback, concurrent with; and

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[1] Initially identified as CREDO approach: Chemical and Radiochemical EPR Design Optimisation.

- A comprehensive analysis to identify and appraise the significant parameters, with a view of taking them into account from the design stage onwards. One of the main aims of the ALARP process in this respect will be to limit the number of chemical and radiochemical specifications to those strictly required to operate the EPR and thereby to determine the best available technique to be implemented.

The ALARP approach is supervised by an EDF engineering and operations expert group, working in close collaboration with AREVA. Their conclusions and recommendations will be submitted to the project for approval as the studies progress, so that they are efficiently integrated into all design elements.

The innovative aspect (related to the chemistry and radiochemistry) of the ALARP approach lies in its evolutionary and preventative aspects as it is the first time it is being applied to optimising the chemical parameters of a PWR unit during the design stage.

It would be premature to indicate the final values of the chemical parameters that will be adopted, at the current stage of the project. Nevertheless, the main features have already been made: they are described in the following paragraphs.

The following topics are split into 3 items in order to explain how the ALARP approach is used on the EPR design for minimising the source term during all periods of operation at power, shutdown and start-up.

- power operation:
  - primary coolant pH management;
  - zinc injection;
  - dissolved hydrogen control; and
  - secondary system chemistry.
- shutdown; and
- start-up.

3.3.1.2.1. During power operation

3.3.1.2.1.1. Primary coolant pH management

The main objectives of the chemical specifications of the primary coolant is to minimise the transport of activated corrosion products, to limit coolant contamination, as well as to reduce operator dose, to optimise the shutdown period that is partly dependent on the quantity of corrosion products released into the primary coolant. Not only should an optimised $pH_{300°C}$ be targeted, but it should also be constant from the start of and for the duration of the cycle. A typical value of 7.2 has been adopted at the current stage of the studies, in the light of the positive operating feedback from the French PWR fleet.

At the beginning of life, the boron-10 (B-10) enriched boric acid will have to be used with sufficient increase in lithium concentration (C_{Li}) to obtain this value. Thus, the permissible maximum lithium concentration has been determined and set at, for example, 4 mg kg^{-1} for UK EPR.

This is considered compatible:

- with the corrosion resistance of the fuel cladding (M5^{TM} alloy), regardless of the management adopted; and
- with materials in contact with the primary coolant.

The target isotopic enrichment in boron-10 proposed for the enriched boric acid will be 37 % atomic. This value accommodates all the fuel management options, provides the anti-reactivity margins required for the safeguard systems, in addition to the nuclear auxiliaries and meets the environmental requirements for boron releases.

It is also useful to have means to enable a constant $pH_{300°C}$ to be maintained throughout the cycle in addition to the intrinsic $pH_{300°C}$ value defined above. This function will be provided at all times, using an automatic LiOH injection device. Its function will be to offset all lithium concentration variations of the primary coolant in real time, by injecting lithium hydroxide in aqueous solution. This device is controlled by a feedback control driven system, by comparison with online boron concentration and lithium concentration measurements in the primary coolant; (measurements are obtained by the Nuclear Sampling System (REN [NSS])). An analogous prototype device has been installed at French Tricastin unit 2 NPP, where it has been running for several cycles. It effectively counteracts load follow effects and consequently observes the target $pH_{300°C}$ set point for the coolant.

The following table summarises the BAT and ALARP main arguments supporting the choices made for the UK EPR as regard as primary coolant pH management:

UK-EPR conditioning	BAT and ALARP consideration
pH program:	
• $pH_{300°C}$: 7,2 (B-Li coordination)	• Optimisation of corrosion product solubility
• Use of Enriched Boric Acid (EBA)	• Reduction of the boron concentration and hence reduction of the lithium concentration needed to reach the expected $pH_{300°C}$. These enable: o Reduction of acid boric discharges; and o Reduction of tritium production and hence tritium discharges.
• $[Li]_{max}$= 4 mg/kg	• Limitation of fuel cladding corrosion risk

3.3.1.2.1.2. Zinc injection

Zinc injection is beneficial to operation of the UK EPR as it:

- Gives a reduction in dose rates;
- Has positive effects on fuel performance;
- Has positive effects on material integrity;

- Has positive effects on wastes and discharges; and
- Has no detrimental effect.

These claims are supported by the following evidences [Ref-1] to [Ref-3]:

- Reduction in dose rates

  This is supported by a global dose rate estimated reduction of 10% to 15% for the UK-EPR. This overall estimation is based on the following international evidences:

  - Reduction of the source term by means of general corrosion minimisation: reduction is estimated to be between 40% and 50% for operating plants in the presence of zinc;
  - Reduction of deposited activity in the primary circuit surfaces due to the Co-60 inhibition and/or replacement by zinc: reduction of Co-60 incorporation is estimated to be about 12%;
  - PWR feedback showing dose rate reductions of 20% to 40% in operating units and 70% for new reactors (Angra feedback); and
  - The average reduction of diffusion and rate coefficients for stainless steel and Alloy 690 is approximately 10%.

- Positive effects on fuel performance and unit availability

  This is supported by:

  - Reduction of the source term by means of general corrosion reduction; and
  - Qualitative reductions observed in the reduction of fuel CRUD according to NPP feedback (about 30%) due to the reduction of residence time on the core and uniform distribution preventing Axial Offset Anomaly and Corrosion Induced Localised Corrosion events.

- Positive effects on material integrity

  This is supported by:

  - Reduction of the source term by means of general corrosion reduction: reduction is estimated to be about 50%;
  - The positive impact on Primary Water Stress Corrosion Cracking (PWSCC) for Alloy 600/304/316 has been evaluated but it has not been showed for Alloy 690/152/52 due to their high corrosion resistance; and
  - In all the cases no detriment effect is identified.

- Positive effects on wastes and discharges

  This is supported by:

  - The expected reduction of general corrosion and hence source term reduction; and
  - The expected reduction of fuel deposits leading to:
    - Reduction of activated corrosion products and hence reduction of activity in liquid discharges and solid wastes, and
    - Reduction of crud accumulation in the spent fuel pool.

  No quantitative assessments of the reduction rate can be provided due to the lack of uniform international data concerning the filters and resins replacement strategy and liquid effluent and discharge management strategies.

Zinc injection will be performed in the UK EPR. Taking into account the extensive PWR feedback and the large amount of work that has been carried out by the international community to optimise zinc injection, the UK EPR can benefit from the positive effects of zinc injection from the first cycle of operation.

The following table summarises the BAT and ALARP main arguments supporting the choices made for the UK EPR as regard as zinc injection.

UK-EPR conditioning	BAT and ALARP consideration
Zinc Injection:	
• Target Values: 5<[Zn]<15 µg/kg	• Reduction of material corrosion and replacement of cobalt on ex-core surfaces. No higher concentrations of zinc are requested due to the choice of material without Stress Corrosion Cracking risk and the use of zinc from the beginning of the operation ➔ Reduction of corrosion products source term and reduction of fuel crud → reduction of nickel, iron, cobalt activation, hence reduction of Co-58, Co-60, Fe-55, Fe-59 production. This enables: o Reduction of cobalt and iron discharges o Reduction of solid wastes (filters and resins)
• Use of depleted zinc acetate	• See justification below this table
• Maximum value: 40 µg/kg	• Conservative value to prevent crud

The choice of the additive used on the UK EPR (depleted zinc acetate ($C_4H_6O_4Zn.2H_2O$)) for zinc injection is the result of a balance between different options.

1) The selection of depleted zinc instead of natural zinc is justified by:

- Zn-65 limitation in the oxide layers of primary circuit surfaces in order to optimise the dosimetry benefit; and
- Zn-65 limitation in effluents and waste.

2) The selection of zinc acetate is justified by:

- The high solubility of acetate when compared with other possible additives (borates and formates) which limits precipitation into the injection lines and allows easier staff chemistry activities concerning the maintenance of the injection system device.
- International experience showing the absence of negative impacts on:
  - Carbon production (negligible production 10^{-4}% of the carbon production from other sources [Ref-3] [Ref-4];
  - Waste production;
  - Filter and resins consumption; and

- o CRUD deposition on fuel cladding: possible decrease of crud accumulation in the spent fuel.

3.3.1.2.1.3. Dissolved hydrogen control

The concentration of hydrogen dissolved in the primary coolant (C_{H2}) is the result of an optimisation study taking into account the following phenomena (see [Ref-1] and PCSR Sub-chapter 5.5):

- water radiolysis;
- hydriding of fuel cladding;
- risk of corrosion under stress with the materials in contact with the primary coolant; and
- control of Corrosion Products production and transport.

The following table summarises the BAT and ALARP main arguments supporting the choices made for the UK EPR as regard as dissolved hydrogen:

UK-EPR conditioning	BAT and ALARP consideration
Hydrogen:	
• Target Values: $17<[H2]<30$ cm^3 (STP)/kg	• Compromise between the minimal concentration required to suppress radiolysis and the optimal concentration to avoid the corrosion product deposition in the core and the corrosion product transport. No higher concentrations of hydrogen are requested due to the choice of material with high PWSCC corrosion resistance. • To limit the hydrogen concentration enables to: o Limit the H_2 degassing in diphasic tanks; and o Reduce the explosion risk.
• Maximum value: 50 cm^3 (STP)/kg	• Lack of data concerning fuel cladding hydriding for higher concentrations

3.3.1.2.1.4. Secondary system chemistry optimisation

The main aims of secondary coolant treatment are to maintain the integrity of the primary and secondary barrier by limiting the steam generator tube corrosion risk and limit the corrosion and flow accelerated corrosion risks of the whole of the secondary cooling system, in order to optimise safety, availability and service life of the future unit.

Chemical treatment consists in implementing a volatile amine associated with hydrazine to obtain the $pH_{\text{at temperature}}$, so that a reducing medium is maintained in the steam generator.

In the absence of pollution, the choice of the pH value in the case of all volatile treatment has little impact on the corrosion of the steam generator tubes, given their grade (690 alloy). However, the pH value will be determined to minimise the risks of flow accelerated corrosion (FAC) of non-alloy or low-alloy materials that make up the secondary cooling system components in the turbine room and reduce oxide transport to the steam generators.

Three fundamental design choices for the secondary cooling system will directly influence the chemical treatment of the EPR secondary cooling system:

- the absence of copper materials;
- the use of stainless steel for elements that are highly sensitive to the flow accelerated corrosion phenomenon (diphasic water/steam medium); and
- no continuous condensate polishing treatment.

Another important aspect to be taken into consideration is the statutory environmental aspect that imposes limits on amine and nitrogen concentrations in liquid discharges. Therefore, the choice of the optimum pH must make allowance for these various input data.

Various amines have been examined in relation to the flow accelerated corrosion phenomenon to reach the optimum pH for the secondary coolant, incorporating the following criteria:

- the stability, nature and effects of thermal decomposition products;
- APG [SGBS] ion exchange resin management;
- the standards for liquid wastes discharged into the environment;
- the consequences of this treatment on steam generator fouling.

The basic options appraisal focuses upon the following amines:

- ammonium hydroxide;
- morpholine; and
- ethanolamine.

A residual ammonium hydroxide concentration will always be allowed for, given the presence of hydrazine and the effect of its thermal decomposition, regardless of which amine is selected for the main treatment (combined treatment). These amines present different properties: basic dissociation constants, distribution coefficient and molar weight.

In summary, at the current stage of the options appraisal the choice of secondary coolant treatment with ethanolamine seems to be preferred. Indeed, it would be more suitable for the following considerations:

- Ethanolamine is a stronger alkali (better dissociated) than ammonium hydroxide and morpholine, thus the quantities involved are smaller. Furthermore, ethanolamine has a better thermal stability than morpholine;
- Environmental impact favourable: nitrogen discharges are lower and no decomposition in nitrosamine; and

- Better limitation of corrosion risks of the whole of the secondary cooling system.

3.3.1.2.2. Shutdown

On the basis of the operating feedback from various countries and theoretical studies on corrosion products behaviour, the recommended cold shutdown procedure following hot shutdown provides:

- the reduction in hydrogen content;
- the removal of lithium from the primary coolant to decrease pH;
- the elimination of fission products from primary coolant (in case of fuel cladding failure) to control the maximum activity directly released to the environment through the stack;
- the removal of oxygen via hydrazine injection just before connection of RIS/RRA trains;
- a forced oxygenation of the primary coolant by injecting H_2O_2; and
- a RCV [CVCS] high flow rate purification. The RCV [CVCS] let-down flow on EPR has been considerably increased for this purpose, in relation to the existing French power plant units, flow at 72 t h^{-1}, thus doubling purification capacity.

Shutdown practices are described in Sub-chapter 5.5 of the PCSR.

The following table summarises the BAT and ALARP main arguments supporting the choices made for the UK EPR as regard as hydrazine and H_2O_2 injections:

UK-EPR conditioning	BAT and ALARP consideration
Hydrazine • used during shutdown and start-up in primary circuit	• Oxygen elimination in complement of TEP4 [CDS] (Coolant Degasification System) degassing • Additive commonly used in operating NPP • No production of effluents since it is eliminated via its reaction in the primary coolant
Hydrogen peroxyde • used during oxygenation	• Corrosion product solubilisation in order to favour the corrosion product elimination • Additive commonly used in operating NPP • The limit use of H_2O_2 does not affect the resins performance • No negative effect on wastes

3.3.1.2.3. Start-up

As regards post-refueling start-up, chemical treatment avoids corrosion risks and also limits the corrosion products source term, primarily by efficiently removing the released nickel from primary coolant.

The following main operating phases are envisaged to do this:

- static and dynamic venting;
- starting the online degasser as early as possible at the maximum flow rate on the RCV [CVCS], to reduce the dissolved oxygen concentration;
- setting the purification unit on the RCV [CVCS] to remove the residual corrosion products at low temperature. The nickel concentration reduction target should aim for below 100-150 µg kg^{-1}, provided the primary coolant temperature has not reached 120°C;
- hydrazine injection from 80°C to remove the residual oxygen, to achieve a criterion of $O_2 < 100$ µg kg^{-1} (see table above for BAT and ALARP main arguments supporting the choices made for the UK EPR as regard as hydrazine);
- total Boron Concentration: value required by fuel management to manage criticality; and
- the hydrogen and lithium hydroxide will be injected into the primary coolant when the reactor has reached the hot shutdown state.

Start-up practices are described in Sub-chapter 5.5 of the PCSR.

3.3.1.3. Controlling the production of tritium

The production of tritium – an intrinsic feature of PWRs – has only a minor health impact due to its low contribution to the total effective dose and its short biological half-life.

The OECD report [Ref-1] states that in the particular cases of tritium and carbon-14 *"Currently, there are no abatement techniques in place to reduce the discharges of tritium and carbon-14".*

However, the control of the initial production of tritium in the reactor, whilst increasing reactor power and efficiency and output, remains one of the environmental priorities of the EPR project.

Tritium is a radionuclide mainly produced by the neutron capture reaction by boron (B-10) and lithium (Li-6) isotopes, chemical species required respectively to control the reactivity and the pH of the primary cooling system. To control the pH, the concentrations of these additives in the reactor coolant are coordinated from one to the other, generally being reduced through the fuel cycle via let-down of the primary coolant and its replacement by non-borated make-up water. The production of tritium from these sources depends directly on the energy produced (neutron flux) and the boron and at a second order lithium concentrations. As the later are reduced through the fuel cycle (boron to control reactivity, lithium to maintain pH) the production of tritium from these coolant additives also decreases. In addition, indirect sources of tritium originate in the fuel itself, by means of ternary fission reactions (more details in Chapter 6 of the PCER).

In the case of the EPR, improvements in terms of increased power, availability and fuel management efficiency have a direct effect on the tritium source term expected.

To limit the increase in tritium effluent caused by the power effect and EPR unit fuel management, the measures used in the previous PWR units have been continued: these include cladding of the fuel rods with a zirconium alloy to limit the diffusion of tritium through the cladding, use of lithium hydroxide enriched with isotope 7. However, in the EPR design the following additional measures to minimise the tritium formed in the reactor have also been implemented:

- Using a significant gadolinium load of burnable poisons (number of gadolinium rods absorbing the neutrons from the nuclear reaction for new fuel loads): this reduces the required concentration of boron-10 in the primary circuit, especially at the start of each cycle (the boron-10 is used to control excess reactivity due to new fuel, over and above that, which can be controlled using the reactor control rods alone). The production of tritium is reduced on a pro-rata basis. The fuel rods containing the gadolinium (Gd) burnable poison have to be downrated but with the number present, this only incurs a small loss in power equivalent to about 2 days electricity production each year; and

- Optimisation of the primary chemistry by boron-lithium coordination. Optimal pH control ensures integrity of primary circuit components (corrosion, etc.) including steam generator tubes but at the same time avoids higher concentrations of lithium that could act as a significant source of tritium (or give rise to other operational problems). In addition, use of lithium hydroxide containing > 99.9 atom % lithium-7 minimises significantly the production of tritium from the lithium-6.

Summary of BAT assessment – Reducing Source Terms Effluents

The techniques for reduction of the effluents source term described above meet several nuclear BAT factors of the OECD report [Ref-1], in particular:

- **Use of low-waste technology**: The reduction of the source term of the effluents contributes to the minimisation of the generation of radioactive wastes from the nuclear facility;

- **Efficient use of resources**: The reduction of the effluent source term, and in particular the reduction of stellites, of cobalt content of materials and alloys, the optimised manufacturing of steam generator tubes and the optimisation of chemistry conditioning during Hot Functional Test as well as the primary and secondary sides water chemistry:

    - Results in the reduction of waste created from the facility, thus improving the eco-efficiency of the nuclear facility (e.g. emissions per GW); and

    - Enables the optimisation of both radioactive and non radioactive impacts and reduces the environmental footprint of the facility.

- **Reduced emissions:** The reduction of the effluent source term, and in particular the reduction of stellites, of cobalt content of materials and alloys, the optimised manufacturing of steam generator tubes and the optimisation of the reactor chemistry conditioning minimises potential radioactive releases from credible accident conditions and their consequences for the environment and reduces worker dose during normal operation.

3.3.2. Designing optimal effluent sorting systems

The principle that there should be progressive reductions in radioactive discharges is central to the UK Strategy [Ref-1] and has been a feature of UK government policy since 1993 [Ref-2]. Linked to this principle is the preference to *“concentrate and contain”* rather than *“dilute and disperse”* set out in the Statutory Guidance of the Department of Environment, Transport and the Regions (DETR [Ref-3]).

Indeed, “*the concentration and containment of radioactive emissions is a central objective of BAT”* as stated in the OECD Report [Ref-4]. That is why, the liquid chemical and radioactive effluent sorting and treatment circuits (treatment techniques are described in the following section) are designed to minimise the activities of liquid effluents that need to be discharged from the EPR and hence their subsequent impacts.

The design efforts aim to optimise the sorting and processing systems, as follows:

- An optimal recycling of borated primary circuit coolant, after it has been let down from the primary circuit (to allow boron dilution for reactivity control). In the EPR, the aerated primary water can be treated and recycled. This has the effect of reducing the volume and activity of the liquid effluent compared to current PWR designs as well as reducing the boron discharges associated with these; and

- An optimal selective collection system for the different liquid effluents in particular the three drain channels that collect leaks and spills from the various plant areas. The effluents can then be treated separately by one or more methods such as evaporation, ion exchange and filtration. This allows a marked reduction in the activities and volumes discharged while optimising the production of solid radioactive waste from the effluent treatment systems (filters, concentrates and resins).

This system has been examined in detail in Chapter 6 of the PCER.

The EPR design differs from current PWR designs by improvement to the selective collection of floor and chemical drains (3 categories of floor drains). Only the most active ‘FD1’ floor drains (potentially contaminated) are expected to require treatment using the 8TEU [LWPS] evaporator. Effluents from the ‘FD2’ floor drains (potentially not contaminated) and ‘FD3’ floor drains (products outside of the controlled area) are expected to routinely require only filtration prior to discharge. Mixing and cross contamination of active FDs with low activity FDs is thus avoided. The EPR's design therefore incorporates design features that greatly facilitate segregation and selective treatments that, at currently operating plants, are more difficult to implement (for example, they require multiple transfers and redirection of effluents through various sumps in the plant to effect selective treatments).

Therefore, at the design stage, the EPR allows a 10% gain at least in the activity discharged in the form of liquid, excluding tritium and carbon-14, in relation to the best French 1300 MW(e) units.

The layout of the EPR unit is expected to involve a central Effluent Treatment Building for solids and liquids that could serve one or more EPR units. The building will be equipped with systems for treating effluent by filtration, demineralisation, evaporation of liquid effluent and also conditioning of solid waste.

Summary of BAT assessment – Sorting and Processing Systems

The sorting and processing systems described above meet several nuclear BAT factors of the OECD report [Ref-4] in particular:

- **Use of low-waste technology**: The optimisation of the sorting and processing systems (in particular optimal recycling of primary effluent and the selective collection of floor and chemical drains) enables the minimisation of the generation of radioactive wastes from the nuclear facility;

- **Efficient use of resources**: The implementation of the selective collection system enables a marked reduction in the activities and volumes discharged, both in terms of liquid effluents and volume of solid waste produced. Altogether, this:

    - Improves the eco-efficiency of the nuclear facility (e.g. emissions per GW); and

    - Optimises both radioactive and non radioactive impacts to reduce the overall environmental footprint of the facility.

- **Reduced emissions:** The segregation of the drains enables the operator to concentrate and contain radioactive and chemical discharges, or other environmentally persistent or bio-accumulative emissions.

3.3.3. Optimisation of treatment techniques for liquid effluents

It is evident that BAT for effluent management need to be implemented first at the design stage of the facilities, but also when considering the technologies used during the treatment of the effluents. Once nuclear plants are built, there are generally fewer opportunities to change the design of the processes, and therefore the focus of optimisation shifts towards improvements in abatement technology. In the case of the EPR, improvements have taken place at both design and operational levels by ensuring that the production of radioactive and chemical effluent is minimised (reduction of the source term, see section 3.3.1) on the one hand, and that efficient mitigation measures for the treatment of the effluent before discharge and the most adequate methods of storage and discharges (see section 3.3.4) are used on the other hand.

The general aim of waste water treatment is to:

- minimise waste water generation;

- minimise radioactive discharges;

- optimise the operations; and

- minimise the dose rate (according to the As Low As Reasonably Achievable (ALARA) principle).

In order to ensure these objectives, the first step consists in optimising the design of the primary auxiliary systems (notably the primary coolant purification systems) as well as their chemistry conditioning and the associated monitoring systems and program [Ref-1]. This enables to minimise waste water generation and to apply appropriate treatment before discharge.

A wide range of abatement technologies for liquid effluents are potentially available for reducing or eliminating emissions, and considered as BAT in the UK. The report from the OECD dated from 2003 [Ref-2] provides a number of examples of these, including:

- chemical precipitation;
- hydrocyclone centrifuging;
- cross-flow filtration;
- ion exchange;
- reverse osmosis;
- ultrafiltration; and
- evaporation.

From an EPR point of view, the objectives pursued for the mitigation of radioactive effluents involve concentrating the radioactivity contained in the liquid effluent into the form of a low volume of solid waste and a diluted, monitored and controlled discharge of residual radioactivity in liquid form, in accordance with the relevant authorisations. This complies with the principle that preference is given to ‘concentrating and containing’ the activity rather than ‘diluting and dispersing’ it, as mentioned above [Ref-3]. The techniques implemented in the treatment of radioactive liquid effluents help to minimise discharges into the environment, either directly by treatment of the effluents prior to discharge, or indirectly by reducing the activity in the primary circuit.

This approach and the processes implemented in the EPR constitute BAT at acceptable cost for the management of liquid radioactive effluents and achieve a balance between gaseous and liquid discharges, generation of solid wastes, practical feasibility of concentrating and containing all streams, worker doses and the public doses and other environmental impacts incurred by discharge, in line with BAT/ALARP principles.

Some, but not all, of the techniques used for the treatment of the EPR liquid effluents include for example:

- enhanced filtration systems for removal of active particulate materials from solution;
- ion exchange systems for removal of selected dissolved active materials; and
- evaporation systems for removal of active materials and soluble and particulate chemical components.

Most of the techniques implemented for the treatment of the effluents arising from the EPR activities involve several steps, including those mentioned above (but not only or all): filtration, demineralisation, evaporation and, in the case of the primary effluent only, degassing operations. These techniques are described briefly below from a BAT point of view. More details on treatment plants and systems implemented in the EPR are available in Chapter 6 of the PCER.

Each liquid effluent treatment technique used in the UK EPR is based on proven design technology which enables the plant not only to match the performance levels in terms of discharges of operating PWRs but also to provide operational flexibility to meet evolving regulatory discharge requirements or changes in practice during the lifetime of the plant.

The waste water treatment systems (i.e. TEP [CSTS], 8TEU [LWPS], APG [SGBS]) of the UK EPR utilise evaporators and/or dead end filtration combined with demineralisers for the removal of suspended and dissolved radioactive solids arising from the primary fluid, waste water and steam generator blowdown water. Individually or in combination these techniques will remove the radioactive nuclides independently if they are in solid or ionic form. While the dead end filtration ensures the removal of virtually all Total Suspended Solids (TSS) the demineralisers remove Total Dissolved Solids (TDS). Evaporators will remove both types of impurities.

Utility experience based on hundreds of PWR operating years has shown that for dead end filtration the combination of filters proposed for UK EPR provides good overall results in terms of finding a balance in minimising discharges, operator dose and secondary waste volumes (filter inserts).

Decades of operating experience demonstrate the efficiency of this development towards reducing discharges. An assessment of the treatment methods and long term discharges of various operating PWR has been carried out and shows that the waste water treatment systems that have been proposed for the UK EPR result in the lowest discharge values [Ref-4].

The water treatment options that have been selected for the UK EPR enable future operators to have a specific and dedicated routing of TSS and TDS to an evaporator, filter and/or demineraliser. The UK EPR design enables discharges to be limited to levels which are amongst international best practice of operating PWRs and provides operating flexibility to meet future regulatory discharge requirements for the OSPAR Convention.

3.3.3.1. Filtration

The aim of the filtering operations is to retain the materials (whether active or not) that are present in suspension. This step has no effect on the chemical composition of the effluent, and enables the reduction of the activity in insoluble form. Several methods of filtration are used in the different processes of the EPR, including pre-filtration steps with fixed grids and trash rakes followed by fine filtration using drums and chain filters. This process is used for both the treatment of chemical and radioactive effluents. In particular, filtration is used for (see Sub-chapter 8.2 - Figure 1):

- The treatment of the primary effluents in the TEP [CSTS]. The primary effluents pass through one filter. This filter (25 µm filter) is used to prevent fine particles of resin escaping into the rest of the treatment system;
- The treatment of the spent liquid effluent in the 8TEU [LWPS]. Filtration is involved in the treatment of all the types of spent fuel effluent (floor drains, chemical drains and process drains), but at various levels:
    - For process drains, filtration is used during the demineralisation stage. An initial filtration step (first on a 25 µm filter followed by a finer 5 µm filter) is used to remove suspended solids from the spent effluent before the effluent passes through the demineralising unit. Another 25 µm filter is fitted after the ion exchange device, preventing fine particles of resin escaping into the rest of the treatment system;
    - For chemical drains, coarse filters are used before the effluent is sent to the evaporation plant. In the evaporation plant, the effluent passes through a 25 µm filtration station before being separated into distillates (only weakly active and/or chemically polluted) and concentrates (containing most of the activity and soluble and particulate chemical components) in the evaporator (see below); and

  - For floor drains, usually only marginally contaminated, 5 µm filtration is used to remove suspended solids potentially present before sending the effluent to the on-site storage tanks pending discharge. This process is similar for the laundry effluents.

- The treatment of blowdown from steam generators. Two filters are fitted in parallel to remove a proportion of the solids suspended in the drained water. An additional filter is fitted after the demineralisation unit to prevent fine particles of resin escaping into the rest of the treatment system.

Experience shows that the use of filters below 1 µm in the RCV [CVCS] can be problematic with respect to the generation of solid waste (spent ILW filters) whilst having minimal additional impact on reducing radioactive liquid discharges or worker doses. The advantage of using filters with filtration level below 1 µm has not been demonstrated on a large scale programme, to date. Filtration in the RCV [CVCS] also seeks to minimise the generation of spent resin by use of pre-filtration to limit the degradation of the resin bed material and downstream filtration to avoid the introduction of fines as impurities in the primary coolant.

For other liquid effluents systems (e.g. TEP [CSTS], 8TEU [LWPS], APG [SGBS] and Conventional Island Liquid Waste Discharge System (SEK [CILWDS]) a range of filter pore sizes are used and pre-filters/strainers are employed to protect micro-filters and minimise the generation of solid waste in the form of spent filters. The filters used in these systems are also amenable to either volume reduction or incineration, which reduces overall solid waste disposals. Using 25 µm pre-filters reduces the clogging and therefore decreases the total filters consumption. This reduction of the waste volume leads to a financial saving, as well as a dose reduction for the workers during the filter replacement. Final filters for discharge are rated at 5 µm and this is consistent with EA guidance for the treatment of liquid effluents from nuclear reactors [Ref-1].

Because in the UK EPR filtration systems the filter inserts can be easily replaced, the pore size of the dead end filters selected and utilised in the UK EPR can be modified by the operator depending on specific requirements and operational experience.

The absolute filter pore diameter provides only criterion for initial filter selection. The filter performance will, in addition to its specific design, also be influenced by throughput, type of particulate, particle size distribution, particle shape and more.

The effective pore size of a dead end filter and its typical removal efficiency will change during its operation as it builds up a filter cake. While the original filter efficiency will remain constant the increasing thickness of the filter cake will itself act as filter media. Hence even TSS smaller than the nominal pore size initially selected will be retained within this additional filtering layer.

In addition, the operating experience shows that decreasing the initial pore size of the dead end filters will have no significant impact on TSS. The reason for this is the previously described filtration effect of the filter cake.

A negative effect is that selection of smaller filter pores will lead to rapidly increasing pressure drop across the filter (fouling) hence requiring a more frequent change of the filter media and consequently produce more secondary waste for disposal.

The filters are changed when the pressure difference reaches a set limit or when a set radioactivity level limit has been reached. This means that the filters are not changed at a regular frequency, but rather as and when required, hence the filters will be used to their full capacity and not wasted. This minimises solid waste arising associated with filtration and is part of the application of BAT.

As experienced by individual reactor operators and anticipated to some extent for every EPR, modifications for filtration systems are expected to be required throughout the lifecycle of the plant as conditions change or through different operational practices. The operator will then have the option to change the filter pore size based on operational feedback.

Filtering operations are also performed for the treatment of chemical effluents, whether or not associated with liquid radioactive effluents. In particular, sewer effluents are treated with on-site scrubbers and oil filters to remove potential hydrocarbons, and filtration is also used for the treatment of seawater in the desalination plant, if any, and the production of demineralised water.

The filtration activities described above employ various types of filter media, and, in the case of radioactive effluents, these are used in conjunction with decay storage and the application of suitable reagents and pH, to ensure precipitation of particular radionuclides. The media generally used are:

- granular media such as sand or alumina of either fixed or varying grain size;
- cloth or paper;
- metal mesh; or
- carbon fibre, porous or sintered metal, and ceramic filters.

Cross-flow filtration and ultrafiltration are two specific aspects of the filtration technique more recently developed (see section 3.3.3.4.1) and implemented in the EPR. However, these are not implemented yet for the treatment of effluents, and are confined to the treatment of seawater in, if any, the desalination plant. Research is currently underway to further use these techniques to remove very low levels of contaminants from liquid effluent and allow high decontamination of radiologically important radioisotopes and good overall beta-gamma decontamination.

All the filtration techniques discussed above for the treatment of effluents are already implemented in nuclear facilities in the UK, and have been identified as BAT by the OECD report [Ref-2] and the IAEA [Ref-3]. In particular, filtration used for the treatment of liquid effluent before storage or discharge complies with a number of BAT principles summarised below.

Summary of BAT assessment – Filtration Techniques

The filtration techniques involved in the treatment of liquid radioactive effluents described above meet several nuclear BAT factors of the OECD report [Ref-2] in particular:

- **Efficient use of resources:** Filtration enables the optimisation of both radioactive and non radioactive impacts thereby reducing the environmental footprint of the facility;
- **Use of low waste technology**: Filtration produces waste into a solid form, more manageable than liquid. In addition, it contributes to the minimisation of waste generation by concentrating the waste arising from liquid effluent;
- **Reduced emissions:** The use of filtration:
  - Concentrates and contains environmentally persistent or bio-accumulative emissions by producing most of the discharge into solid form; and therefore;
  - Reduces trans-boundary geographic displacement of environmental impacts by reducing the spread of the activity (for example in the sea).
- **Use of less hazardous substances:** Filtration enables the conditioning and immobilisation of radioactive effluents into a more easily monitored and retrievable waste form for interim or final disposal.

3.3.3.2. Demineralisation

The demineralising operations involve passing the effluent through resin beds that fix the elements present in ionic form in the effluent. This technique is in particular used for the treatment of radioactive effluent to remove very low levels of contamination, but also for the production of demineralised water and, if one is present on site, in the desalination plant. The life of a demineralisation unit is however considerably reduced by chemical pollution.

Such operations will be used at several levels in the EPR, both for the treatment of radioactive and chemical effluents. In particular, they will be involved in (see Sub-chapter 8.2 – Figure 1):

- The treatment of the primary effluents in the TEP [CSTS]. Two mixed-bed demineralisers containing resins are fitted between the two sets of filters described above, enabling the reduction of the activity of the primary effluent;
- The treatment of the process drains in the 8TEU [LWPS] (active effluents but containing little chemical contamination). This demineralisation step retains soluble materials (active or not) but lets most of the boron pass through. The other spent effluents (chemical and floor drains) do not routinely undergo a demineralisation step as they are not considered active enough to require it. In addition, the process drains demineralisation operations may also be bypassed if the effluent is of low activity and chemical content.

When treated, the process drains (active effluent, chemically clean, aerated and borated) are treated by standard demineralisers in the 8TEU [LWPS]. These are of three different types to optimise removal of ions from the effluents:

- Strong high-capacity gel-type cationic resins which have a large exchange capacity;
- Strong high-capacity anionic or macro-porous resins which retain large molecules and colloids and allows for increased exchange rates when necessary; and
- Mixed-bed-type.

The choice retained for the UK EPR is one high-capacity cationic bed, one high-capacity anionic bed and one mixed bed. Each bed can be by-passed. This enables flexible treatment, for example if there is a problem with one of the beds it will allow for maintenance to be carried out on the bed without interruption of the treatment process; it also allows flexibility in dealing with specific pollutants (notably silver), as one bed can be used for a specific treatment if necessary. By-pass lines can be isolated and hence the effluents can be routed via the demineralisers in a specific order.

The minimal and maximal volumes of the demineralisers are calculated based on the velocity, the loading per hour and the dimensions of the bed. The quantity of resin per bed is then optimised with regards to the space left for maintenance and the frequency of the replacement. The volume determined for the Flamanville 3 EPR is 2.1 m^3 and the replacement frequencies are approximately 1.5 years for the cationic and anionic beds and yearly for the mixed bed. Using the maximum volume would not bring about a significant gain in the reduction of the frequencies.

A pre-filter is installed before the demineralisers (that removes a proportion of the solids). After passing through the demineralisers, the effluent is filtered again to prevent fine particles of resin escaping into the rest of the treatment system;

- The treatment of the blowdown of the steam generator. Two lines each containing two filters (that remove a proportion of the solids in the blowdown water), followed by two resin-filled demineralisers, are fitted in parallel for the treatment of the blowdown in the APG [SGBS] blowdown circuit. After passing in the demineraliser, the effluent is filtered again to prevent fine particles of resin escaping into the rest of the treatment system. After purification, the blowdown water is sent to the condenser where it is recycled. It may also be sent to storage tanks prior to discharge (T (0KER [LRMDS]) or S (0TER [ExLWDS]) tanks), if the tritium concentration in the secondary circuit is to be lowered, or if the condenser is not available. If the treatment system (APG [SGBS]) is not available, the blowdown water may be sent directly to the storage tanks before discharging (T (0KER [LRMDS]) or S (0TER [ExLWDS]) tanks);
- Although not directly linked to the treatment of effluents, ion exchange resins are also used for the treatment of chemical effluents in the desalination plant if any.

Ion exchange media usually implemented in UK nuclear installations are either made of [Ref-1]:

- Organic resins, which can carry various functional groups that provide a cation or anion exchange effect; or

- Inorganic ion exchangers, some of which act as adsorbers rather than ion exchangers and, to make them more efficient, are fabricated into beads or microporous gels with a high surface area.

These are the media also used in the EPR, and the use of ion exchange resins for the demineralisation process is an approved technique in the UK. In particular, these techniques are considered as BAT in light of the recommendations of the Nuclear Energy Agency [Ref-2] and the IAEA [Ref-1], as summarised below.

Summary of BAT assessment – Demineralisation Techniques

The demineralisation techniques involved in the treatment of liquid radioactive effluents described above meet several nuclear BAT factors of the OECD report [Ref-2] in particular:

- **Efficient use of resources:** The use of ion exchange resins and thus the concentration of the activity on the resins enables the reduction of the environmental footprint of the facility by optimising both radioactive and non radioactive impacts;

- **Use of low waste technology:** The demineralisation operations and the use of ion exchange resins enable:
  - The minimisation of radioactive waste generated by concentration of the activity; and
  - The creation of waste into a manageable solid form (sorbed onto the resins);

- **Reduced emissions:** The use of ion exchange resins concentrates and contains environmentally persistent emissions, hence progressively reducing emissions and impacts.

3.3.3.3. Evaporation

The evaporation step of the effluent treatment involves evaporating the liquid effluent and then condensing the purified distillate in order to discharge it, with the condensate constituting the treated waste. This technique therefore concentrates the activity and chemical elements present in the treated effluent into a reduced volume. The distillate has a significantly reduced concentration of radioactive and chemical products (with the exception of tritium). Evaporation is a technique mainly used on effluents containing significant contamination, and is used after pre-treatment of the effluent by other techniques such as filtration and demineralisation. In particular, evaporation is used in the overall treatment of (Sub-chapter 8.2 – Figure 1):

- The primary effluents after they have undergone the filtration-decontamination and the degassing stage in the TEP [CSTS] circuit.

The evaporator separates the primary coolant into a bottom concentrate containing boric acid concentrate (4%) and the distillate containing distilled water and any volatile constituents carried over in the distillation process (such as tritium). The concentrates are sent to the Reactor Boron and Water Make-up System (REA [RBWMS]) for reuse in the primary circuit after treatment. The distillates are sent to the T (0KER [LRMDS]) (or S (0TER [ExLWDS]) tanks via the 8TEU [LWPS] or back to the Coolant Storage and Treatment System (TEP [CSTS]) for reuse in the primary circuit.

- The chemical drains after they have been coarse filtered. Similarly to the primary effluents, the 8TEU [LWPS] evaporator (distinct to that used for primary coolant in the TEP [CSTS]) separates the spent effluents into distillates (only weakly active and/or chemically polluted) and concentrates (contain most of the activity and soluble and particulate chemical components). The distillates are subsequently sent either to a storage tank or back to the evaporation system for additional treatment, and the concentrates, to the 8TES [SWTS]. Process and floor drains can also sometimes be treated by evaporation in this evaporator unit.

In the UK, evaporation is not used at any NPP, and although Sizewell B is equipped with one it has never been operated. In the US and Sweden the use of evaporation is limited and gradually being reduced. Germany achieves the lowest discharges but has sufficient evaporative capacity in the TEU [LWPS] of the Konvoi reactors to treat all effluent arisings regardless of its composition. This is the practice for other PWR plants in Germany in order to achieve the lowest discharges of all the countries assessed. This is not the practice in France where the criteria for evaporation ensures that it is only used for effluents incompatible with demineralisation and with sufficient radioactivity content to justify the impact of evaporation, such as solid waste generation, worker doses, etc.

However, there is considerable flexibility in the operation of the UK EPR so discharges will be mainly influenced by the way it is operated. The required performance of the operation of the 8TEU [LWPS] is also site specific; the release to rivers of a given quantity of radionuclides results in higher doses to members of the population than the release to the open sea. The design of the EPR 8TEU [LWPS] allows performing either as the Konvoi plants or consistently with the French practice with respect to operational liquid releases. Whether the evaporator is used during operation is the decision of the operator. The operator has to decide, whether the balance between energy costs, amount of solid waste to be managed and release to the water body is optimised.

Nevertheless, like filtration and ion exchange techniques, evaporation is already implemented in the UK in various nuclear installations. In particular, when used in conjunction with other techniques, it enables the removal of contaminants from liquid effluents, usually prior to final discharge into the environment. This technique has been identified as BAT in the UK for existing nuclear installations [Ref-1] [Ref-2] and it complies with the following BAT management factors for optimisation of discharges from nuclear installations as summarised below.

Summary of BAT assessment – Evaporation Techniques

The evaporation techniques involved in the treatment of liquid radioactive effluents described above meet several nuclear BAT factors of the OECD report [Ref-1] in particular:

- **Use of low waste technology:** Implementing an evaporation stage in the treatment of effluent from nuclear power stations enables the minimisation of the generation of radioactive wastes from the facility by concentrating the activity into the concentrate; and
- **Reduced emissions:** The use of evaporation techniques in the treatment of liquid effluents concentrates and contains environmentally persistent or bio-accumulative emissions and radioactive discharges by segregating the effluent into concentrate and distillate, and thus contributes to progressively reducing emissions from power stations.

3.3.3.4. Techniques under development for potential future use for the treatment of the EPR liquid effluents

It is essential to remember that the concept of BAT relies on optimisation of the processes, facilities and methods of operation of an installation in order to maximise protection of the environment by improving the techniques implemented on site and thus progressively reduce emissions from the facility. As such, technical developments are required to be reviewed and implemented where appropriate. EDF is committed to this process and research and development is ongoing to improve existing or develop new treatment methods for potential future implementation in the EPR. This, along with the improvement of the operational techniques, would contribute to progressively reducing emissions from the facility and responds to one of the BAT management factors.

3.3.3.4.1. Treatment of radioactive effluents by membrane technologies: ultrafiltration and reverse osmosis

It has been established that techniques such as cross-flow ultrafiltration and inverse osmosis can significantly reduce the activity discharged from a nuclear installation, without creating large volumes of waste. These techniques are currently in use in nuclear installations in the UK and elsewhere in the world [Ref-1], and are usually recognised as BAT. They will be implemented in the EPR if a desalination unit for the production of demineralised water is needed, but research is currently undergoing to determine their potential for the treatment of radioactive effluents. It is potentially possible that microfiltration or ultrafiltration could also be used for the treatment of effluents containing insoluble particles, and that reverse osmosis could be used to separate water from dissolved materials [Ref-2]. This is already the case, on a small scale (generally in the laboratory) in a number of countries all over the world including the UK.

Cross-flow, microfiltration and ultrafiltration are filtration techniques involving the use of porous membranes (0.01 to 2 µm) to retain suspended material of larger size than the pores. The effluent flows over the membrane due to a pressure gradient, and filtration occurs perpendicularly to the flow (as in conventional cross-flow filtration).

Ultrafiltration could be used for the treatment of effluents of low activity and low boron content (floor drains and laundry effluents) in place of evaporation which produces larger volumes of concentrates. The use of ultrafiltration would only retain suspended materials (dissolved materials pass through), generating much smaller waste volumes than the use of an evaporator, and would also avoid the very energy-consuming step of changing the physical state of the effluent to treat (liquid to gaseous). A drawback of using ultrafiltration would however be a smaller decontamination factor than with evaporation, as dissolved materials would not be retained. This is not expected to be a major issue, due to the low levels of contamination of these effluents, and therefore it is envisaged that ultrafiltration would allow sufficient decontamination. In addition, ultrafiltration could be used as a pre-treatment stage prior to demineralisation of the effluents on ion exchange resins, although this is not the current process. This additional preliminary stage would increase the life of the ion exchange resins.

Reverse osmosis could be used in the future for the treatment of effluent containing dissolved materials. Indeed, this technique relies on the ability of some membranes to allow for solubilisation and dissolution of solutes, and their diffusion through the membrane. In reverse osmosis, a pressure is applied to the solution of lower concentration in the element to treat, and diffusion occurs along a concentration gradient from the least concentrated solution to the most concentrated solution. The implementation of this technique is similar to the implementation of microfiltration or ultrafiltration, and this technique is commonly established in the UK as well as elsewhere in the world and recognised as BAT [Ref-1] [Ref-3] for treatment of conventional effluents.

Reverse osmosis could potentially be used for the treatment of effluents of high activity and with high boron content in the future, and would provide a high decontamination factor along with potential recycling of boric acid from process and/or chemical drains.

Although these techniques are implemented elsewhere in the UK and the rest of the world, usually on a small scale basis and in the laboratory, they still need to be validated by an experimental programme for use on a larger scale in the EPR, in particular to determine compliance to ALARP principles during periodic changing of the membranes. Therefore they are not expected to be implemented in the EPR at first, but their use may be envisaged in the future.

3.3.3.4.2. Treatment of radioactive effluents by electrolysis

Electrolysis is currently used in a number of facilities for treatment of liquid effluents. It relies on the movement of electroactive radionuclides through a conductive solution before these can be deposited on an electrode. This technique, particularly suitable for corrosion products that can then be deposited onto the cathode, would concentrate the activity present in solution in a small volume (on the cathode).

Electrolysis is currently expected to be used in the EPR for the treatment of the chemical effluents and the production of sodium hypochlorite. However, it is forecast that it could also be used to remove some elements out of solution (the technique has proved to be particularly efficient for the removal of silver-110m), and/or to optimise the volume of waste produced [Ref-1]. In the first instance (use for removal of silver-110m), the technique would be used in addition to ion exchange resins that have low efficiency in removing this radioelement. Utilisation for waste volume limiting purposes would involve treating the liquid spent effluent concentrate in order to limit its activity (a threshold value is imposed by the regulators on this concentrate).

In addition to its potential use for radioactive effluent treatment purposes, electrolysis has proved to be particularly useful for breakdown of hydrazine from the secondary circuit. However, financial costs are currently still a hurdle for its implementation at this stage.

This technique, although promising, does have a number of limitations, in particular related to its requirement to be implemented on conductive effluents only, and its inefficiency on some radionuclides such as caesium. In addition, the overall decontamination factor is generally low and the cathodes after deposition can become highly active, implying potential high doses for the operators and difficulties to apply to the ALARP principle. Therefore the treatment requires the use of another technique.

However, once a number of drawbacks described above have been resolved, it could be envisaged that this technique is used for the treatment of radioactive effluents in the future. If implemented, its use would comply with a number of BAT principles, in particular the efficient use of resources, the use of low waste technology and the use of less hazardous substances.

3.3.3.4.3. Treatment of radioactive effluents by isotopic retention

A relatively novel technique, isotopic retention, has recently been developed and could be implemented in the future in the EPR for treatment of some radionuclides and chemicals within effluents [Ref-1]. This technique involves an electrochemical process using a metallic catalyst directly in contact with the effluent, which enables selective migration of isotopic species to occur. Results from preliminary experiments carried out on this process have shown, after one or two weeks, a reduction to a high degree (40 to 90%) of the activities for the following isotopes: tritium, cobalt-58, cobalt-60, silver-110m and antimony-124. Some significant reduction of the carbon-14 activity has also been observed, although these preliminary results would need to be confirmed. It has also proved useful in the removal of chemical compounds such as morpholine or ammonium, implying that it could be used for the treatment of secondary circuit chemicals present in the effluents.

This technique is currently being implemented on a small scale basis in a nuclear site in Sweden, and could potentially be implemented in the UK in the mid-term future. A number of issues are however to be solved at the optimisation stage of the design such as:

- lack of consistency of the preliminary results obtained;
- a filtration stage following this process would be required due to the use of a suspended catalyst (for better efficiency);
- the technology implies the generation of chemical species in solution such as Na^+ or other metallic cations; and
- the catalyst is expensive and, once used, generates waste that can be difficult to dispose of.

Overall, once these technical issues are resolved, the technique could be implemented in the EPR. Due to the low level of development so far, it has not undergone a full BAT assessment. However, it is evident that it would answer a number of BAT requirements, in particular as it enables to significantly reduce the activity of a number of specific isotopes.

3.3.3.5. Conclusion: Optimisation of treatment techniques for liquid effluents

The abatement technologies implemented in the EPR for the treatment of the effluents (in particular filtration, demineralisation and evaporation) are all in current use in the nuclear industry worldwide and have already been implemented in the UK, in particular at Sizewell PWR power station. They have various efficiencies on different materials, and, in particular, some radionuclides are better removed than others (i.e. there are no current abatement techniques to reduce levels of tritium and carbon-14 in effluents). They are generally recognised as BAT independently of each other, and have been identified as relevant and reliable. In addition, in light of increasing pressure to reduce the discharge of radioactive and other materials into the environment, it is evident that substantial advantages and higher decontamination factors can be accrued by selecting a combination of two or more processes and their consecutive or simultaneous application for treatment of liquid waste [Ref-1] [Ref-2]. This is true for both preparing effluents for discharge and condition concentrated wastes for disposal. These processes usually involve treatment by filtration, precipitation, sorption, ion exchange, evaporation and/or membrane separation.

The approach adopted by EDF and AREVA for the EPR is in line with these requirements of combining several techniques to achieve higher rates of decontamination and to reduce discharges as far as possible. In addition, it is generally admitted that operators may seek to argue that the adoption and implementation of EA guidance and relevant good practice represents BAT without more detailed consideration of options and techniques. This approach is acceptable providing that the operator demonstrates that the guidance and good practice is relevant and fully applicable to the facility in question. Therefore, although full BAT analyses have not been carried out for the techniques involved in the treatment of the effluents in the EPR, it is considered that, as the techniques have been approved elsewhere in the UK for similar installations, the BAT analysis carried out for the EPR would lead to the same conclusion.

Additional BAT requirements imply that, in order to obtain the authorisations to discharge radioactive substances in the UK, the operators shall keep abreast of new abatement and treatment technologies. This is in particular to improve the transparency of the decision making process. Some examples are given above to show EDF and AREVA’s strong desire to develop new techniques and always ensure that technological developments continue to be reviewed and implemented where appropriate. However, it is believed that the techniques currently envisaged to be implemented for the treatment of the liquid effluents in the EPR are the best available at the current time, although it is expected that they will be periodically reassessed and potentially replaced or added to by the more advanced techniques currently under development in the future. This is consistent with the BAT approach requiring ongoing optimisation and assessment of the treatment techniques in use, and consideration that a best available technique for a particular process will change with time in the light of technological advances, economic and social factors, as well as changes in scientific knowledge and understanding.

To summarise, the techniques to be implemented for the treatment of liquid effluents in the EPR:

- have already been implemented for similar purposes at other nuclear sites in the UK and worldwide;
- answer a number of nuclear BAT management factors for optimisation of discharges from nuclear installations;
- have generally been identified as BAT by the Nuclear Energy Agency [Ref-2]; and
- are periodically being reassessed against newly developed techniques.

In other words, and in accordance with the guidance of the EA, it can be considered that the techniques implemented for the treatment of liquid effluents and described above are BAT.

3.3.4. Designing storage systems and discharges adapted to the site

The systems for storing and discharging the liquid radioactive effluents are on the one hand designed to check and quantify the activity of the effluent before discharging it, and on the other hand to minimise the impact of liquid radioactive effluent on the environment by achieving optimal dilution and dispersion.

These planned storage and discharge tanks will offer very substantial hold up capacity with sufficient capacity to cover all reactor operating scenarios. They will also offer buffer capacity in the event of faults.

The operators can also optimise the use of the storage capacities offered by the various reservoirs before discharge to sea or to an estuarine environment. In particular, they will offer the option for extended hold up of discharges allowing increased radioactive decay of short lived nuclides such as iodine-131 and cobalt-58 over and above that possible in current lower capacity storage systems.

The measures adopted to reduce the effect of thermal discharges into the sea will also be effective in promoting maximum dilution of liquid radioactive effluent and thus reducing its environmental impact.

Summary of BAT assessment – Storage and Discharge Systems

The storage and discharge systems described above meet several nuclear BAT factors of the OECD report [Ref-1] in particular:

- **Use of low-waste technology**: The storage and discharge systems implemented on the EPR will minimise the discharge of radioactive wastes from the nuclear facility by allowing increased radioactive decay of short lived radionuclides in storage tanks;
- **Efficient use of resources**: The storage and discharge systems will enable:
    - The minimisation of generation of radioactive waste which in turn will improve the eco-efficiency of the nuclear facility (e.g. emissions per GW); and
    - Optimal dilution and dispersion of the liquid effluents, thus optimising both radioactive and non radioactive impacts to reduce the environmental footprint of the facility;
- **Reduced emissions:** The use of storage tanks to allow for increased radioactive decay of short lived nuclides contributes to:
    - Contain radioactive and chemical discharges by gathering all effluents in the same place; and
    - Progressively reducing discharges and emissions.

3.4. GASEOUS RADIOACTIVE DISCHARGES

The measures implemented to limit the impact of gaseous discharges from the operating activities of the EPR result both from the design of the plant and the operational practices implemented. Design features use BAT to minimise gaseous discharges at source and similarly in abatement plant, at acceptable costs, and balance worker doses incurred during treatment in the plant with public doses from discharges. At the operational level, systems and plant are managed and used in a manner so as to minimise environmental impacts of discharges, ensure all discharges are monitored and recorded and all fall within the required regulatory limits. The operations will be subject to the ISO 14001 requirements.

Various provisions allow gaseous radioactive waste to be reduced in the EPR design. These centre on reduction at source (waste minimisation), containment within plant and recycling where possible. In addition, treatment is implemented to ensure that most hazardous isotopes are removed from effluent streams and contained within solid filters. Delay beds are also used to allow decay of short lived species. Finally suitable monitoring is carried out and residual gaseous effluents are discharged via a stack designed to ensure maximum rapid dispersion and dilution in the air. The height of the EPR discharge stacks will be determined for adequate diffusion of these discharges, taking into account of local site topography and wind patterns.

The minimisation of radioactive waste in gaseous discharges in the EPR starts with minimisation of activity at source and consequent movement in the primary circuit liquid coolant. This has already been described in the previous section. Once the liquids pass into other systems and outgassing occurs, a range of design features ensure abatement of the gases and associated discharges in accordance with the most recent best operational experience and plant design features.

The EPR's Gaseous Waste Processing System TEG [GWPS] design is similar to that of Konvoi reactors. In particular, this system has the advantage of being able to treat aerated gases and to operate in an almost closed loop in normal operation.

Furthermore, in the EPR, the implementation of a metallic liner on the inner wall of the Reactor Building (RB) limits the infiltration of radioactive gases into the annulus (depressurised by the Annulus Ventilation System (EDE [AVS]) collection system, consisting of three extraction lines equipped with very high efficiency filters and pre-filters).

In addition, three other design features permit the reduction of the radioactive gaseous effluent at source in relation to current French PWR designs:

- the absence of pneumatic valves in the Reactor Building;
- the absence of an intermediate TEP [CSTS] tank; and
- an optimised ventilation/filtration system.

These features are described below.

3.4.1. Gaseous Waste Processing System TEG [GWPS] functions

Gaseous fission products are generated in the core, including isotopes of xenon and krypton. A fraction of these gases are released into the primary coolant in the event of a defect in the fuel cladding.

Hydrogen is added to the primary coolant via the RCV [CVCS] to control the oxygen.

Since these gases are dissolved in the primary coolant, they are transported to the other systems during fluid transfers.

Given the explosive nature of hydrogen in the presence of oxygen and the radioactivity of the gaseous fission products, the presence of these gases in the various auxiliary systems is monitored.

The TEG [GWPS] performs the following functions:

- It offsets the variations in free volume in the tanks (connected to the TEG [GWPS]) caused by transfers into or out of the tanks;
- It contains the radioactive gases by keeping most of the system under negative pressure;
- It performs nitrogen flushing, and treats the gaseous effluent resulting from degassing of the primary coolant in the tanks;
- It limits the hydrogen content in the system and in the connected components to 4% by volume to avoid formation of an explosive mix, and limits oxygen content to 0.1% by volume to minimise the corrosion effect (absorption of the oxygen by the primary coolant). After recombination, the concentration in the purging gas is lower than 0.3% by volume for hydrogen and 0.1% by volume for oxygen;
- It manages the excess gas produced in the connected system during reactor transients; and
- It retains the noble gases during the decay phase to meet authorised limits on discharge to the environment.

3.4.2. An optimised Gaseous Waste Processing System TEG [GWPS] [Ref-1]

The EPR's design provides a significant reduction in discharges of gaseous radioactive waste, due to the design of the TEG [GWPS]. The main improvements which allow this are:

- Sharing TEP [CSTS] and REA [RBWMS] tank ullages: limiting the volume of the gaseous waste in normal operation (constant gaseous balance when water is moving);
- Continuous nitrogen flushing of the tank ullages and head spaces: lowering the hydrogen content allows increased standardisation and flexibility in the treatment of off gases from tanks, etc, whether their compositions are dominated by hydrogen or oxygen;
- Recycling gases: limiting the volume of the gaseous waste in normal operation;
- Recombination of hydrogen in the off gas from tanks, etc. into water. This also retains the majority of tritium and iodine isotopes in an aqueous phase;
- Decaying the short-lived gasses (mainly xenon and krypton) from the TEG [GWPS] system on absorbent charcoal delay beds; and

- Automatic discharge into the discharge stack as soon as a threshold pressure (that can be modified (setpoint) according to the volumes of gas to be treated), is reached, which allows the system's storage capacity to be maximised according to plant operating mode (especially just prior to and after shutdown when fission product spiking from the fuel can occur).

3.4.3. Absence of pneumatic valves in the Reactor Building

The absence of pneumatic valves in the Reactor Building allows the gaseous waste originating from this building to be reduced. Discharges will be limited to those required in support of the maintenance or commissioning the building Containment Sweep Ventilation System (EBA [CSVS]).

3.4.4. Reducing gaseous Tritium discharge

In the current 1300 MW(e) French designs, there is intermediate flushing of the TEP [CSTS] tank that is the source of ~80% of the tritiated gaseous effluents in discharges from these plants. To minimise this source of tritium, the EPR uses the alternative N4 system for the collection and treatment of primary circuit coolants as these are let down from the circuit over the operating cycle. As a result, this source of tritium is removed, and in the EPR the bulk of the tritium in gases originates from evaporation from the fuel pools.

3.4.5. An improved Ventilation/Filtering system

All of the ventilation systems for the Nuclear Auxiliary Building (NAB), Safeguard Building (SB), Fuel Building (FB) and the controlled areas of the Effluent Treatment Building (ETB) can be routed to iodine traps prior to discharge. This is in contrast to the current 1300 MW(e) plants where only selected plant areas in the Nuclear Auxiliary Building can be so routed. In addition, in the EPR design, all the rooms with special cells (2 for the Fuel Building, 3 for the Nuclear Auxiliary Building, and 1 for the Safeguard Building) pass through High Efficiency Particulate Air (HEPA) filters that can be routed to the iodine traps.

3.4.6. Conclusion on reduction of gaseous radioactive discharges

The design characteristics provide the following qualitative improvements:

- Due to the absence of Reactor Building depressurisation, radionuclides remain in the installation and are released during unit outage (improvement related to releases associated with Reactor Building depressurisation, except for long-lived radionuclides); and

- During unit outage, Nuclear Island ventilation is comparable to 1300 MW(e) units, with improvements in permanent releases due to degassing of aerated piping by TEG [GWPS] (improvement for xenon-133 and xenon-135 releases due to degassing of piping, and for all iodine isotopes and other radioelements released from the system). Reactor Building and TEG [GWPS] sweeping during unit outage generates releases comparable to 1300 MW(e) units.

Depending on the condition of the primary system ('clean', 'dirty', i.e. in case of a few cladding defects, or 'very dirty', i.e. in case of several cladding defects), potential improvements (essentially due to the new TEG [GWPS] design) are variable, but on average they amount to approximately 20% for inert gases and iodine isotopes, and 15% for other gaseous discharges.

Nevertheless, for these types of releases, the impact of operating contingencies (fuel cladding leak tightness) on the radiochemistry of the primary system (and therefore on gaseous releases) is of great importance.

In addition, it should be noted that gaseous abatement techniques implemented by the EPR are focused upon technologies considered as best available technologies as mentioned in the OECD Report [Ref-1].

Indeed, this report states that modern gaseous abatement techniques mainly focus on three technologies:

- Dry HEPA filtration to remove particulate actinide aerosols; these are implemented on the EPR (see above);

- Wet gas scrubbing to remove soluble fission product particles and some gases such as carbon dioxide; these are not implemented on the EPR because:

    - Wet scrubbers are used essentially to treat off-gases from radioactive waste incinerators; and

    - Carbon dioxide represents only 20% of carbon-14 gaseous discharges produced in the EPR. The major part of carbon-14 is discharged as methane (CH_4) which does not react with the aqueous sodium hydroxide solution used in the wet gas scrubbing process.

- Carbon adsorption technologies (carbon filter beds) to remove volatile chemically reactive gases such as iodine isotope; these are implemented on the EPR (see above).

Summary of BAT assessment – Gaseous Radioactive Discharges

The techniques and systems involved in the treatment of gaseous radioactive effluents described above meet several nuclear BAT factors of the OECD report [Ref-1] in particular:

- **Use of low-waste technology**: The implementation of systems such as the TEG [GWPS], or the absence of pneumatic valves allow for the minimisation of the generation of radioactive wastes from the nuclear facility. Discharges of tritium are also reduced, and the implementation of iodine traps enable a reduction in the overall gaseous discharges;

- **Use of less hazardous substances:** Implementation of systems such as iodine traps and improved ventilation and/or filtering systems enable the operator to:
    - Condition and immobilise unstable discharges forms into a passively safe state; and
    - Monitor and record discharges.

- **Efficient use of resources**: The overall reduction of gaseous discharges contributes to:
    - Improved eco-efficiency of the nuclear facility (e.g. reduced emissions per GW); and
    - Optimisation of both radioactive and non radioactive impacts thereby reducing the environmental footprint of the facility, in particular by using delay beds to allow for decay of short lived species or a stack designed to ensure maximum rapid dispersion and dilution in the air.

- **Reduced emissions:** The improvements in the gaseous treatment systems contribute to the progressive reduction in discharges and emissions, and ensure that suitable monitoring is carried out prior to discharge.

4. EVALUATION OF THE EXPECTED PERFORMANCE AND MAXIMUM DISCHARGES AND BENCHMARKING AGAINST EXISTING UNITS

Note: The consent process for a specific site will require dedicated limits to be assessed based on the chosen site specific data and constraints.

4.1. PRINCIPLES FOR THE EVALUATION OF THE EXPECTED PERFORMANCE AND MAXIMUM DISCHARGES

This section describes the principles used for the evaluation of the expected performances excluding contingency and maximum discharge values of the EPR. In addition, it compares these principles with the regulatory principles and their implementation for setting limits on radioactive discharges to the environment from nuclear-licensed sites, as determined by the EA [Ref-1].

Within this section, two sets of quantitative targets for both radioactive and non radioactive discharges to the environment for liquid, solid and gaseous waste are considered:

- The ‘expected performance excluding contingencies’. This corresponds to estimated discharges under nominal operating conditions without significant contingencies in the form of plant excursions; and
- The ‘maximum discharge value’. This corresponds to the estimate of maximum discharge of the Unit, under normal operating conditions but also taking account of a range of transient conditions (but ignoring faults or accidents). These maximum discharges offer a head-room over and above those for standard operation at power stations. They are required to allow operational flexibility to the plant operators when, for example, moving the plant between different operating modes (especially start-up and operation at power and shutdown).

In the case of some non radioactive discharges, this method has been adapted on an individual basis. Specific discharge scenarios have been defined for these substances, taking into account transient conditions to determine the limit.

4.1.1. General principle

The expected performance of the EPR is calculated using reference values derived from OEF and applying an EPR design-based improvement factor.

The process comprises three steps:

- Definition of reference values based on experience feedback;
- Assessment of EPR design-based improvements (taking into account the increase in power produced and the increased availability factor Kd of the EPR over the 1300 MW(e) reactors); and
- Determination of forecast discharge values for expected plant performance and maximum discharge values.

OEF is used as the baseline since it is more realistic than theoretical assessments (given the complexity of the production, treatment and release chain). In particular, the optimisation of radioactive discharges applied for several years to the nuclear plants in use has indeed shown that it is possible to significantly reduce radioactive discharges through operating strategies. EPR discharge values are therefore estimated based on the most realistic reference values.

The values thus obtained for the EPR and OEF values are then compared on the basis of annual discharges and annual discharges per unit of energy produced. The second comparison (annual discharge per unit of energy produced) is preferred to compare the performances, as it is linked to the power produced and thus allows the comparison across different types of plants.

The use of OEF to determine reference values is considered to be in line with the best practices required by the EA. Indeed, the EA generally considers three basic types of initial input when setting discharge limits, specifically [Ref-1]:

- The baseline of past plant and site discharges;
- Future plant operation, including continued operation of existing plant, plant closure, new plants, dealing with legacy waste and decommissioning of plant at the end of its operational life; and
- Improvement schemes that will be implemented during the period of authorisation.

4.1.2. Definition of references values based on OEF

The recent OEF from discharges from 1300 MW(e) units is used as the reference to define the forecast radioactive discharge values for the EPR unit. The 1300 MW(e) series were chosen as the reference because they provide more complete and stabilised experience feedback than the N4 plant series (more recent 1450 MW(e) plants).

The period from 2001 to 2003 was chosen for the following reasons:

- It is sufficiently recent to be representative of current plant fleet performance;
- It is sufficiently well documented, particularly taking into account new calculation methods; and
- It is sufficiently long to allow smoothing of contingent effects.

Eight sites were considered over a three-year period. Given these data, two options could be considered for the calculation of the discharge performance values:

- Use the statistical distribution of the 24 values obtained from the analysis of 8 sites over 3 years (expressed per unit); or
- Use the statistical distribution of eight average values for each site over the three-year period (expressed per unit).

It was decided that the second option would be implemented as it takes better account of the site operating conditions and represents a performance managed over time. The statistical distribution thus obtained is not as scattered as it would be using the other method and gives a more realistic approach of the phenomenon.

In the case of radioactive discharges, the distribution of the 8 values (eight 1300 MW(e) sites) for these annual average discharges will be expressed in Bq per unit (calculated over the 2001-2003 values), and the distribution of the 8 elements (eight 1300 MW(e) sites) for the average discharges will be expressed in Bq per kWh (net unit produced).

The performance reference value adopted for the EPR is the first quartile[2] derived from this statistical distribution (eight average values for each site over the three-year period). Given the dispersal of some results and the environmental objectives defined for the EPR, using only average values to determine the reference value was not considered sufficient. On the other hand, the opposite approach involving the systematic use of the best performance as the reference was considered unrealistic (particularly due to the normal variability in operating performance from one fuel cycle to another).

Although this is not generally the case, for some radionuclides the assessment is supplemented with a more detailed analysis based on experience from three 1300 MW(e) plants (Golfech, Cattenom and Penly) including a full cycle for each unit considered. This analysis enables the determination of the distribution of effluents based on their origin and on the operations conducted, thereby permitting the evaluation of the advantages expected with EPR design-based improvements. Golfech and Cattenom[3] were chosen because they provide a number of usable datasets and Penly because it is a coastal site.

For the gaseous effluent analysis, three pre-Konvoi or Konvoi units[4] were also considered: GKN2 (Neckarwestheim-2), and KKI2 (Kern-Kraftwerk Isar-2) over the year 2001 and KKP2 (Kern-Kraftwerk Philippsburg-2) from 1996 to 2002 (2002 in particular due to high primary activity).

In the case of carbon-14 and tritium, given the phenomena from which they originate and the absence of an industrial treatment system, assessments were theoretical and mainly based on source term estimates.

The approach adopted for the determination of the performance reference values is a comparative approach. It is based on real discharge values for the existing plant fleet (rather than discharge authorisations) and therefore permits the assessment of the main differences between discharges from 1300 MW(e) and EPR units under equivalent conditions so as to identify definite and sufficiently quantifiable improvements.

For some discharges other than radioactive, the method described above was adapted on a case-by-case basis due to a reduced statistical distribution that did not allow undertaking of the same process. In particular, alternative scenarios have been adopted taking into account the transitory periods to determine the expected performance and the limits.

4.1.3. Assessment of EPR design-based improvements

To achieve a realistic assessment of radioactive discharge values for the EPR, a pragmatic approach was adopted, consisting of comparing the EPR design with those of existing units and considering the decisive components of the production, treatment and release chain. From there, a factor representing the design-based improvements of the EPR was determined.

This comparative approach comprises the following steps:

- Comparison of primary source terms;

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[2] Given the small number of terms in the distribution (8 average values per site), the value adopted for the first quartile lies between the 2nd and 3rd term, depending on the technical relevance of rounding off.

[3] For the gaseous effluent analysis, the Cattenom site was considered over the period from 2001 to the first semester of 2002. This site was interesting because two units were affected by fuel cladding problems during that period.

[4] German nuclear power plants

- Identification of main discharge paths, and quantification for existing plant fleet (step strongly relying on analysis of experience feedback);

- Comparison of discharge path designs for EPR and existing plant fleet; and

- Assessment of influence of EPR design changes on estimated discharge values for each path.

4.1.4. Determination of forecast discharge values for expected plant performance and maximum discharge values

4.1.4.1. Expected performance excluding operating contingencies

In order to calculate the expected performance of the EPR (i.e. estimated average discharge), the factor representing EPR design-based improvements and determined using the assessment described above is applied to the reference values obtained from previous experience of the 1300 MW(e) fleet.

It is essential to differentiate these estimated average discharges, which are the values intended to be attained in normal operation, with the operating limits set in line with the maximum discharge values and the regulators' requirements.

The EPR performance for discharges that are not directly proportional to power production is calculated by applying the EPR design-based improvement factor to the first quartile of the distribution in Bq per unit, or, as mentioned above, by developing a new scenario to be determined on a case-by-case basis. When an evident link between power production and discharges can be identified (e.g. carbon-14), the performance is analysed with respect to reference values and expressed in terms of specific quantities dividing them per unit of energy produced (Bq per kWh).

The following EPR power output values are used:

- 4500 MW(th);

- 1735 MW(e) gross; and

- 1630 MW(e) net.

For the purpose of the calculations, a net power output of 1320 MW(e) is used for the 1300 MW(e) unit.

The availability factor Kd generally allows the comparison of the performances with the energy produced. The following conventional reference values will be used:

- Kd for 1300 MW(e) unit, first quartile = 85%;

- Kd for EPR = 91%;

- Reference annual energy production for 1300 MW(e) unit, based on Kd: 1320 x 8760 x 0.85 = 9800 GWh; and

- Reference annual energy production for EPR unit, based on Kd: 1630 x 8760 x 0.91 = 13,000 GWh.

This yields to a 23% increase in net power output and a 33% increase in annual energy production for the EPR.

The robustness of this systematic optimisation method has been verified based on the first quartile value for each discharge, leading to the conclusion that the performance values thus defined are ambitious but theoretically achievable.

4.1.4.2. Maximum discharge values

The maximum discharge values must include a margin based on expected performance values so as to cover all normal operating conditions, e.g. small leaks, system drainage for equipment maintenance purposes or adaptation of water chemistry to meet operating specifications. Previous experience has been used to set this margin as close as possible to that for in-service units, in line with EA requirements.

In the same manner as the expected performance values, the maximum discharge values for the EPR are defined based on the maximum discharge values for 1300 MW(e) units, applying design-based improvements and taking into account the increased power production of the EPR when appropriate. This method enables the definition of an optimised margin for EPR, similar to that for existing units.

4.1.5. Compliance with the EA’s requirements for setting discharge limits and levels for new plants

The approach undertaken by the EA for the determination of annual limits takes account, amongst others, of a factor relating to ‘worst case’ average discharges and a factor representative of the average 12-month plant discharge (based on the monthly discharges of the previous five years). In addition, the overall EA approach for the determination of annual limits allows for caps to be set.

In the case of new plants, the Statutory Guidance [Ref-1] requires that the annual limits are capped at the levels set when approval is first given for full operation, while allowing for reconsideration in the light of operating experience. Reconsideration of these caps will be dealt with at a further stage in BPM and/or BAT determinations. In addition, for new nuclear installations, it is advised that *“worst case discharges are based on the operator’s flow sheet data (…). Benchmarking against similar plant elsewhere is carried out where possible, to provide input to establishing worst case discharges* [Ref-2]”.

In the present situation for the EPR, the preliminary approach described above and developed for the assessment of expected performances without contingency and maximum discharges is consistent with the approach recommended by the EA for the determination of annual discharges.

4.2. BENCHMARKING OF EXPECTED LIQUID AND GASEOUS RADIOACTIVE DISCHARGE VALUES FOR EPR

4.2.1. Liquid discharges

4.2.1.1. Radioactive discharges excluding Tritium and Carbon-14

4.2.1.1.1. Iodine isotopes

The estimation for liquid discharges of radionuclides other than tritium and carbon-14 from the EPR has been carried out using operational experience of three 1300 MW(e) sites over 3 years. The 1300 MW(e) average annual discharges of iodine isotopes for the first quartile have been estimated around 0.7 MBq per kWh produced, which is considered to be a very low value and corresponds to low threshold limit. As no major design changes having an impact on the overall iodine isotope liquid discharges have been made to the EPR compared to a 1300 MW(e) unit, it is expected that these values would remain similar for both installations. An expected performance without contingency of 7 MBq y^{-1}, and a maximum limit of 50 MBq y^{-1} are therefore considered for liquid iodine isotopes discharged from the EPR (see Sub-chapter 8.2 - Table 2). Although these absolute values are similar to those expected for a 1300 MW(e) unit, they represent a 25% reduction when they are compared to the energy produced by both units (MBq per Wh.y, see Sub-chapter 8.2 - Table 1).

4.2.1.1.2. All other beta or gamma emitting radionuclides

For all the other radionuclides (fission and activation products), a performance without contingency of 0.6 GBq y^{-1} and a maximum discharge of 10 GBq y^{-1} are expected from the EPR (see Sub-chapter 8.2 - Table 2). This represents an improvement of 25% on the expected performance value, and up to 40% of the maximum discharge value per MW(e) for all fission and activation products, compared to the production in a 1300 MW(e) unit.

Comparison of these values with discharge values at other nuclear sites in the UK, and Sizewell B in particular, can be difficult. Indeed, historically at Sizewell B, the key radionuclides identified in liquid effluents were tritium, cobalt-58 and cobalt-60, and caesium-138. Tritium has been identified to be responsible for over 20% of total discharges (it actually accounts for over 99%), which is the reason why a limit was set on it (see section 4.2.1.2). Before 2005, all other radionuclides (including iodine isotopes and beta or gamma emitting radionuclides) were considered together for limit discharge purposes, and also identified as giving the greatest dose contribution from liquid discharges [Ref-1]. However, caesium-137 was also identified as a good indicator of how well the site was or is managing its liquid wastes. This is because, during times when there are fuel leaks in the reactor core, caesium-137 forms a significant proportion of the ‘other radionuclides’ discharged from the site. It has therefore recently been proposed to set a limit on the discharges of caesium-137, and to consider it as an extra radionuclide to be measured and reported (along with tritium and ‘other radionuclides’).

Recent values reported for Sizewell B [Ref-1] show that the activity of liquid discharges for caesium-137 averaged at 5 GBq y^{-1} with a peak at 13 GBq y^{-1} (these values relate to a fixed calendar rather than rolling years). The average rolling annual discharge for all other radionuclides at Sizewell B has been 37 GBq y^{-1} since the start of operation (including caesium-137 discharges), and the peak rolling annual discharge has been 67 GBq y^{-1}. If caesium-137 is considered separately to the other radionuclides (and tritium), it was established [Ref-1] that an annual limit of 20 GBq y^{-1} on this particular radionuclide should be imposed. This would also imply that the annual discharge limit for other radionuclides should be reduced in order to take into consideration the new segregation of caesium-137, and it was proposed to set a new limit for ‘other radionuclides’ at 130 GBq y^{-1} (reduction of 70 GBq y^{-1} from the initial discharge limit).

When comparing these values reported for Sizewell B to the expected values for the EPR (see Sub-chapter 8.2 - Table 2), it is clear the latter would provide a large reduction of the activity discharged in liquid effluents due to all radionuclides excluding tritium and carbon-14. In particular, it was estimated [Ref-2] that the limits normalised to 1000 MW(e) for liquid discharges of beta and gamma radionuclides excluding tritium are almost 20 times higher at Sizewell B than for the EPR (109 GBq at SZB, 6 GBq for the EPR).

These estimations can provide evidence that the EPR complies with a number of BAT principles for the discharge of halogens and fission products. In particular, the values suggest that the EPR enables the efficient use of resources by improving the eco-efficiency of the facility.

4.2.1.2. Tritium

Operational feedback from the existing units has enabled to expect an annual performance without contingency for the tritium liquid discharges of the EPR around 52 TBq y^{-1}, with a maximum value of 75 TBq y^{-1} (see Chapter 6 of the PCER). This represent a slight increase (around 4%, see Sub-chapter 8.2 - Table 1) compared to the average value obtained for the first quartile of the 1300 MW(e) reactors (when considering a 2.2 ppm Li chemistry for 1300 MW(e) and 3.5 ppm Li for EPR).

The liquid discharges of tritium at Sizewell B power station have been analysed [Ref-1], and given as a table for the years 1998–2003 [Ref-2]. Over these five years, the authorised annual discharges for tritium were set at 80 TBq y^{-1}, twice as much as the original limit of 40 TBq y^{-1}. This large increase in the discharge limit was necessary as the site was experiencing a number of difficulties at the time, in particular with the secondary neutron sources, and the tritium discharges were high and increasing.

During this time, annual tritium liquid discharges at Sizewell B averaged at 49 TBq y^{-1}, with a peak at 78 TBq y^{-1}. Overall, it is now estimated that the production of tritium at Sizewell B, over an 18-months full fuel cycle produces around 60 TBq of tritium. Considering the uncertainties associated with this estimation and the fact that a ‘worst case’ discharge of 80 TBq in liquid effluent during the course of a year is inferred, it was suggested in 2006 that the set annual limit for tritium at Sizewell B (80 TBq y^{-1}) was acceptable. This limit is still in force, although it may be reduced after reviewing more recent site data. Indeed, it is apparent that tritium production has decreased since the replacement of the secondary neutron sources. However, as there is limited experience with these sources, the EA will review their approach in potentially reducing the tritium discharge limit as they obtain more information on the new sources.

Overall, and considering the enhanced power production of the EPR compared to Sizewell B, it is evident that the EPR presents an improved performance for the tritium liquid discharges normalised to power output (see Sub-chapter 8.2 - Table 2). Details are given in section 0. In particular, it was estimated by the EA [Ref-3] that the liquid discharges of tritium normalised to 1000 MW(e) are over 50% lower for the EPR than for Sizewell B (43.23 TBq y^{-1} estimated for the EPR, 67.23 TBq y^{-1} for Sizewell B). This reduction of tritium discharge for each MW(e) produced demonstrates the ability of the EPR to use resources efficiently, and complies with the BAT principle of improving the eco-efficiency of the facility (i.e. reduced emissions/GW).

4.2.1.3. Carbon-14

Carbon-14 discharges have been estimated for the EPR using operating feedback data from 1300 MW(e) reactors in France. For these reactors, the annual calculated discharges of carbon-14 average is between 15.5 and 16.2 GBq, equivalent to 1.76 Bq/kWh. A similar estimation carried out using measured discharge values suggests an average annual discharge of carbon-14 of 11.5 GBq for the 1300 MW(e) units. It is important to highlight that there are no treatment methods (such as filtration) implemented in the PWRs for the treatment of carbon-14 in liquid effluents, and therefore that all carbon-14 produced is discharged.

It is also important to note that France is the only country in Europe where carbon-14 discharges in liquid effluents are monitored and limited. As such, no values have been reported for the discharges of carbon-14 at Sizewell B.

The production of carbon-14 is directly proportional to the size and power production of a plant; therefore the total carbon-14 discharges for the EPR are expected to be higher than for any of the existing PWRs. In addition, carbon-14 production is essentially due to the flux irradiation of the oxygen-17 contained in the water and, to a smaller extent, of the nitrogen contained in the primary coolant. The amount of carbon-14 produced depends on the water volume subject to flux, the reactor power output, and the nitrogen content of the primary coolant. One difference between the EPR design and that of 1300 MW(e) units is the implementation of a nitrogen blanket (no longer hydrogen) for various tanks (including the volume control tank). This design choice addresses the reduction of the hydrogen risk by a larger use of nitrogen (nitrogen concentration in the RCV [CVCS] tank will be controlled and monitored), and can explain the slightly higher values expected for the EPR.

Calculations and operational feedback have indeed estimated that the performance for the liquid discharges of carbon-14 from the EPR during normal operation is expected to be around 23 GBq y^{-1}, with a maximal discharge value expected at 95 GBq y^{-1} (see Sub-chapter 8.2 - Table 2). Although these values are higher than in the case of other existing PWRs, and considering the increased power production of the EPR compared to other PWRs, the overall carbon-14 discharge per unit of energy produced are expected to be very similar to the values obtained for the 1300 MW(e) reactors (see Sub-chapter 8.2 - Table 1). In addition, and as mentioned above, the slight increase in the expected carbon-14 production results from safety considerations to reduce as much as possible the hydrogen risk by using nitrogen, which represents an important improvement on the design.

4.2.1.4. Conclusion: liquid discharges

The above comparison of the expected performances of the EPR with average values of 1300 MW(e) units and with values obtained from operational feedback at Sizewell B suggest that, for all radionuclides in liquid discharges except tritium, the EPR presents an improvement or similar values to other plants for the expected performances without contingency and discharge limits (see Sub-chapter 8.2 - Table 1 for comparison with 1300 MW(e) units and Sub-chapter 8.2 - Table 2 for comparison with Sizewell B values). In the particular case of carbon-14, the emissions in liquid discharges are not monitored at Sizewell B and therefore comparison is impossible. Overall, the activity thus discharged in liquid effluent is expected to be much lower than for existing installations (carbon-14 and tritium discharges taken apart). It is therefore possible to conclude that the EPR meets a number of BAT principles such as the efficient use of resources or reduced emissions.

4.2.2. Gaseous discharges

4.2.2.1. Radioactive discharges excluding Tritium and Carbon-14

The estimation of gaseous discharges of radionuclides other than tritium and carbon-14 has been carried out similarly to the liquid discharge estimate, using an in-depth analysis of the operation feedback of three 1300 MW(e) sites over 3 years, and a less extensive analysis of the operation feedback of three Konvoi sites. For all radionuclides excluding tritium and carbon-14, the average gaseous discharges provided by the operation feedback from the 1300 MW(e) sites proved to be very scattered. The determination of the expected performances of the EPR from the operational feedback data for these gaseous discharges was not as straightforward as for some other radionuclides, in particular due to a number of design changes, such as the implementation of the TEG [GWPS] adopted from the Konvoi design. Various calculations have been carried out in order to determine these values as accurately as possible.

4.2.2.1.1. Noble Gases

Calculations to estimate the EPR discharges of noble gases have lead to an expected performance (excluding contingency) value of 0.8 TBq y^{-1}, and a maximum value around 22.5 TBq y^{-1} (see Sub-chapter 8.2 - Table 2). This expected performance value is similar to the value obtained from the first quartile of the best 1300 MW(e) units, and the maximum value represents an improvement of 27% from the 1300 MW(e) values per energy unit produced (GWh; see Sub-chapter 8.2 - Table 1).

Regarding the gaseous discharges of noble gases at Sizewell B, operational data showed that [Ref-1] the peak rolling twelve-month discharge value reached 17 TBq (annual discharge limit prior to 2005 = 300 TBq y^{-1}). Predicted discharges calculated for future operation suggested in 2005 that a reduction of the annual discharge limit from 300 TBq y^{-1} to 30 TBq y^{-1} would still provide sufficient headroom for operations at Sizewell B, and therefore a reduction of the annual limit was required by the EA. Even so, when comparing these values to the EPR expected performance and maximum values for the discharge of noble gases (respectively 0.8 TBq y^{-1} and 22.5 TBq y^{-1}), it is evident that the EPR would again provide an improvement over the existing unit at Sizewell B. Values normalised to 1000 MW(e) for both Sizewell B and the EPR suggest that discharge limit should be twice as low for the EPR as they are for the PWR at Sizewell B (annual discharge limits of noble gases normalised to 1000 MW(e) are estimated at 25.2 TBq y^{-1} for Sizewell B and only 12.97 TBq y^{-1} for the EPR [Ref-2], see Sub-chapter 8.2 - Table 2).

4.2.2.1.2. Other fission and activation products/beta emitting radionuclides associated with particulate matter

The performance of the EPR for discharges of other gaseous fission and activation products (i.e. gaseous discharges excluding tritium, carbon-14, iodine isotopes and noble gases) was not extrapolated over OEF reference values, since these discharges are so low that the measurement threshold values were considered instead. Calculations therefore estimated the EPR expected performance at 4 MBq y^{-1}, similar to the value obtained for the existing 1300 MW(e) units. The EPR maximum discharge value was estimated around 120 MBq y^{-1}, representing a 27% improvement over the existing 1300 MW(e) units per energy unit produced (see Sub-chapter 8.2 - Tables 1 and 2).

Comparison of expected performances and limit discharges of the EPR and the OEF data at Sizewell B is not always meaningful but can however provide some information. In particular, the operational experience feedback at Sizewell B [Ref-1] provided information on previous, current and future discharges and a proposition for setting new limits for gaseous discharges.

Up until 2005, limits on gaseous discharges at Sizewell B were set on beta emitting radionuclides associated with particulate matter (along with carbon-14, iodine isotopes, noble gases and tritium). However, in order to be consistent with the requirements of the EU Commission [Ref-2], it was suggested in 2005 that a new limit on cobalt-60 associated with particulate matter should be set to replace the limit on beta emitting radionuclides associated with particulate matter. This was decided to remove the dependency of assessed activity on the assessment technique. However, this suggestion of setting a new discharge limit at Sizewell B was rejected by the EA and the idea abandoned.

The analysis of experience data prior to 2005 showed that the rolling annual discharge of beta emitting radionuclides associated with particulate matter at Sizewell B averaged at 9.5 MBq y^{-1}, with a peak value at 20 MBq y^{-1}. In light of these results, it was suggested that the previous discharge limit on beta emitting radionuclides associated with particulate matter should be reduced from 10 GBq y^{-1} to 100 MBq y^{-1} in order to reflect operational data.

The comparison [Ref-3] of the EPR annual discharges to air with Sizewell B limits normalised to 1000 MW(e) suggests that discharges of other beta or gamma radionuclides would be marginally higher for the EPR (0.2 GBq y^{-1}) than for SZB (0.08 GBq y^{-1}, see Sub-chapter 8.2 - Table 2). However, this discrepancy can be explained by two factors. Firstly, there has been a difference in operational procedures and variation in reporting monitoring results (see Sub-chapter 8.4). The EU Commission Recommendation [Ref-2] states that:

"The determination of detection limits, decision thresholds, and the expression of results should comply with international standard ISO/IS 11929-7. For practical reasons, even though technically the decision threshold is below half the detection limit actually achieved for a measurement, the decision threshold may conservatively be taken to be equal to one half of the detection limit. Where measurement outcomes are below the decision threshold, these outcomes should conservatively be substituted by one half of the decision threshold".

However, the approach adopted for the EPR is more restrictive than the approach recommended by the EU Commission. When measurements are below the decision threshold, they are reported as the decision threshold (equivalent to one half of the limit of detection) as opposed to being one half of the decision threshold (i.e. equivalent to one quarter of the detection limit) as recommended by the EU. In addition, the EU Recommendation [Ref-2] also states that *"if repeated measurement outcomes in the period considered are all below the decision threshold, then it is reasonable to assume that the true value is zero, i.e. that the radionuclide is not present in the discharge"*. For the EPR, for the reference spectra, the measurements are always reported as the decision threshold even if they are consistently below the limit of detection.

As already mentioned, the EPR expected performances were extrapolated using measurement threshold values, as opposed to OEF values. Considering that beta particulate is not normally measurable above the limit of detection (and therefore that the values reported are generally the sum of many samples at the limit of detection), the variations in monitoring procedures described above can partly explain the need for additional headroom in the determination of the EPR discharge limits of other gaseous fission and activation products, and the requirement to set a higher limit for the EPR than the one currently in force at Sizewell B.

Secondly, the analysis of the OEF of the existing 1300 MW(e) units shows that discharges of beta-emitting particulate matter can increase in the event of fuel leaks. In absence of fuel leaks, the concentration of fission products is expected to be at the very ambitious level of the expected performance. Even though fuel leaks can be assumed to be very unlikely, a provision is taken into account so that the concentration of fission products in the coolant may be higher than the best estimated values.

4.2.2.1.3. Iodine isotopes

An expected performance value of 50 MBq y^{-1}, and a maximum limit of 400 MBq y^{-1} have been determined for the EPR for the discharge of gaseous iodine isotopes, representing an improvement of around 20% as compared to 1300 MW(e) units (per energy produced), and 25% over the maximum discharge value per MW(e) produced by a 1300 MW(e) unit (see Sub-chapter 8.2 - Table 1).

Regarding the gaseous discharges of halogens at Sizewell B, it was reported in 2005 [Ref-1] that the limit of 3 GBq previously set may not be the most adequate. Indeed, an analysis of operational experience feedback reported that an annual discharge of halogens exceeding 3 GBq may be possible for one or more of the following:

- Discharges as the result of out gassing from reactor coolant water samples and from venting of system components with the presence of some failed fuel;
- Greater discharges if the station were to operate at the limits defined in the Technical Specifications;
- A bypass of the carbon bed delay system with gas passing into the Radwaste Building HVAC stack at levels approaching the alarm threshold for protracted periods; and
- Discharges of iodine-132 due to tellurium-132 decay, in combination with one of the above.

On this basis, it was suggested there may be benefits in changing the limit for halogens at Sizewell B to one for gaseous iodine-131 alone, as discharges of this radionuclide are considered to be representative of discharges of halogens. A limit on this radionuclide is understood to adequately control exposures from such discharges, and it was suggested in 2005 that a 500 MBq rolling twelve-month limit should be set. The maximum discharge value estimated for the iodine isotopes for the EPR is marginally lower than the proposed maximum limit for iodine-131 at Sizewell B (400 MBq vs. 500 MBq, see Sub-chapter 8.2 - Table 2). This is even more obvious when comparing the annual discharges normalised to 1000 MW(e); the EA [Ref-2] estimated such discharges at 0.42 GBq y^{-1} for Sizewell B but only 0.23 GBq y^{-1} for the EPR. The EPR therefore presents a clear improvement over the existing plant at Sizewell B for the discharges of gaseous iodine isotopes.

Overall, the estimations discussed above can provide evidence that the EPR complies with a number of BAT principles for the discharge of iodine isotopes and noble gases. In particular, the values suggest that the EPR allows efficient use of resources thereby improving of the eco-efficiency of the facility.

4.2.2.2. Tritium

Operational experience feedback from the existing 1300 MW(e) units over the period 2001-2003 shows that the annual expected discharges (excluding contingency) of gaseous tritium vary from 0.77 TBq to 1.86 TBq, with a first quartile at 91 Bq per kWh. These values, along with considerations of the design modifications between the EPR and the 1300 MW(e) units, have lead to an estimate of the annual expected performance of the EPR of 0.5 TBq y^{-1} for the discharges of gaseous tritium. This represents a decrease of 60% compared to the 1300 MW(e) units per MWh produced (see Sub-chapter 8.2 - Table 1). Similarly, the maximum discharge limit has been assessed at 3 TBq y^{-1} for the EPR, representing a 45% improvement compared to a 1300 MW(e) reactor for the same energy produced.

Operational feedback experience at Sizewell B reported in 2005 that the average twelve-month discharge for gaseous tritium was around 0.8 TBq, and that a maximum of 1.9 TBq y^{-1} had been observed, for a discharge limit of 8 TBq y^{-1}. It was however predicted that the annual discharge limit should be reduced from 8 TBq y^{-1} to a more appropriate value of 3 TBq y^{-1}, which would still provide operational headroom between the actual levels of discharge expected during normal operation and the limit. Values normalised to 1000 MW(e) power output provide evidence of the improved performance of the EPR; the EPR gaseous tritium discharges are expected to be over 30% lower than at Sizewell B [Ref-1] (2.52 TBq y^{-1} expected at Sizewell B vs. 1.73 TBq y^{-1} expected for the EPR, normalised at 1000 MW(e), see Sub-chapter 8.2 - Table 2).

This, considering the enhanced power production of the EPR compared to Sizewell B, demonstrates an improved performance for the tritium gaseous discharges normalised to output. This reduction of tritium discharge for each GWh produced demonstrate the ability of the EPR to efficiently use resources, and complies with the BAT principle of improving the eco-efficiency of the facility (i.e. reduced emissions per GW).

4.2.2.3. Carbon-14

The annual average discharges of gaseous carbon-14 for the existing 1300 MW(e) units have been calculated using operational feedback over the period 2001-2003, and values between 210 and 250 GBq have been reported (equivalent to 24 Bq per kWh). This operational feedback applied to the EPR specification led to an expected performance excluding operational faults of 350 GBq y^{-1}, which is just over 10% higher than the annual performance of an existing 1300 MW(e) unit for the same energy produced (see Sub-chapter 8.2 - Table 1). This slight increase in carbon-14 gaseous discharges can be explained by safety reasons (implementation in various tanks, including the volume control tank, of a nitrogen blanket to replace hydrogen. This design choice addresses the reduction of hydrogen risk, see section 4.2.1.3). A maximum discharge limit in gaseous carbon-14 of 700 GBq y^{-1} is also expected for the EPR, which is, for the same energy produced, similar to the value for a 1300 MW(e) unit.

Analysis of the operational feedback data for the gaseous monitoring of carbon-14 at Sizewell B provided an average rolling annual discharge over the period considered (until 2005) of 170 GBq y^{-1}, with a peak of 320 GBq y^{-1}. Calculations on expected future discharges, predict the future twelve-month discharges of carbon-14 to be in the range of 300 to 500 GBq y^{-1}. In light of these results, it was suggested in 2005 [Ref-1] that the annual limit for the discharge of carbon-14 at Sizewell B should be reduced from 600 to 500 GBq. Values normalised to 1000 MW(e) are therefore expected to be higher for the EPR (420 GBq y^{-1} for Sizewell B limit normalised to 1000 MW(e) vs. 405 GBq y^{-1} for the EPR normalised at 1000 MW(e) [Ref-2], Sub-chapter 8.2 - Table 2).

4.2.2.4. Conclusion: gaseous discharges

The above comparison of the performances of the EPR with those of 1300 MW(e) units and with values obtained from operational feedback at Sizewell B suggests that, for most radionuclides in gaseous discharges, the EPR presents either similar expected performances or a clear improvement of expected performance discharges and discharge limits. The activity thus discharged in gaseous effluent is expected to be much lower than for existing installations (carbon-14 and other beta emitting radionuclide discharges taken apart). It is therefore possible to conclude that the EPR complies with a number of BAT principles such as the efficient use of resources or reduced emissions.

Summary of BAT assessment - Estimation of Annual Liquid and Gaseous Radioactive Discharges and Discharge Limits

The determination of the estimations of expected performances and maximum discharges of gaseous and liquid radioactive effluents described above meet several nuclear BAT factors of the OECD report [Ref-1] in particular:

- **Efficient use of resources:** The discharge values for the liquid and gaseous discharges (except carbon-14 and Fission Product/Activation Product (FP/AP)) estimated for the EPR predict an improvement of the eco-efficiency of the facility for each GW produced; and

- **Reduced emissions:** The expected liquid and gaseous discharge values and limits calculated for the EPR (except carbon-14 and FP/AP) will be lower than for existing units, thanks to design improvements. In addition, the operational feedback and periodical review of the procedures in place will participate to the progressive reduction of emissions during the operational phase.

5. DESIGNING COOLING WATER INTAKE AND DISCHARGE STRUCTURES

The approach undertaken for UK EPR is to optimise discharge and water intake during the site specific phase of the project. Indeed, the design of the structures involved is strongly linked to the local environment of the facility and therefore cannot be decided upon at the Generic Design Assessment (GDA) stage. Although this is a site specific aspect to be dealt with at a later stage, UK EPR design will aim to meet the following points:

Summary of BAT assessment - Cooling Water Intake and Discharge

Although cooling water intake and discharge are not directly related to the production of radioactive or non radioactive substances, improvements made on the EPR design are geared towards answering some of the environmental principles to be achieved by installations using BAT, in particular:

- **Efficient use of resources**: The processes in place will enable to reduce the local intake of fresh water; and
- **Reduced emissions:** The processes in place in the EPR will:
  - Reduce the temperature of the cooling water discharged;
  - Improve the dilution factor after discharge of the cooling water; and
  - Reduce the speed of water intake and therefore its impact on aquatic life.

6. REDUCING THE FRESHWATER CONSUMPTION

The primary water consumption station is needed to produce demineralised water to satisfy process requirements.

The fundamental objective is the reduction at source of the requirements for filtered fresh water and demineralised water.

In terms of demineralised water requirements, the EPR unit is fitted with a chemical conditioning system for the water station at the start-up stage in order to provide better quality water (fewer harmful species returned into the steam generators and therefore limited deconcentration bleeds APG [SGBS] and make-up at water stations limited to a single refill). This provision reduces the water consumption at the start-up stage by 30% (in relation to the installed power). In normal operation demineralised water consumption (in relation to the installed power) is compared with a 1300 MW(e) unit. Considering the very site specific aspect of this issue, more details will be given at the site specific stage of the project.

Summary of BAT assessment - Freshwater Consumption

Although the technology in place in the EPR to reduce freshwater consumption is not directly related to the production of radioactive substances, it is in harmony with several nuclear BAT factors of the OECD report [Ref-1] in particular:

- **Use of low-waste technology:** The processes in place will very significantly reduce discharges such as pre-treatment sludges (essentially iron hydroxide) resulting from the usual process of filtration by flocculation;

- **Efficient use of resources:** The processes in place in the EPR should enable reduction of the local intake of fresh water;

- **Reduced emissions:** The processes in place in the EPR will very significantly reduce the filtration discharges - effluents from the regeneration of ion exchange resins; and

- **Use of less hazardous substances:** The processes in place will enable reduction of chemical discharges.

7. CONCLUSION

Sub-chapter 8.2 - Table 1 summarises the environmental performances of the EPR in comparison with the 1300 MW(e) units.

All the arrangements taken at the design stage of the EPR will enable the plant to achieve environmental improvements in terms of abstraction (freshwater consumption), gaseous and liquid discharges (radioactive and chemical) and solid waste when compared to the existing facilities with the exception of tritium and carbon-14.

For these radionuclides which cannot be contained by treatment, the design and operational decisions allow discharges to be maintained at the same level (by energy produced) as the existing facilities and into the form with the least impact (liquid for tritium and gaseous for carbon-14).

It is thus believed that the discharges of the EPR have reached their lowest achievable limits without implementing extensive changes of methods and/or facilities. Applying the ALARP principle and implementing the BAT will remain an ongoing consideration throughout the design, operating and decommissioning phases, and, at the present stage, the processes implemented or proposed to be implemented in the EPR are compliant with the BAT requirements as set out by the Regulators. This ensures that, considering the current techniques available, EDF and AREVA will not have to implement any further reasonable practicable improvements.

Sub-chapter 8.2 - Table 1: Environmental performances of the EPR

Environmental Domainduring normal operation	EPR Performances	Comparison with 1300 MW(e) unit Factor by energy produced
Gaseous radioactive discharges (GBq y^{-1})	Tritium: 500	➘ 60%
	Carbon-14: 350	➚ 12% (5)
	Iodine isotopes: 0.05	➘ 20%
	Noble Gases: 800	➘ 27%
	Other Fission Products (FP)/Activation Products (AP): 0.004	➘ 27%
Liquid radioactive discharges (GBq y^{-1})	Tritium: 52,000	➚ 4%
	Carbon-14: 23	➔ equal
	Iodine isotopes: 0.007	➘ 25%
	Other FP/AP: 0.6	➘ 25%
Chemical discharges (kg y^{-1})	Acid boric: 2,000	➘ 53%
	Hydrazine: 7	➘ 30%
	Morpholine: 345	➔ equal
	Phosphates: 155	➘ 30%
Solid waste and spent fuel	Cladding and end-piece materials	➘ 26%
	Radioactive waste	➘ 40%
	Uranium consumption	➘ 17%

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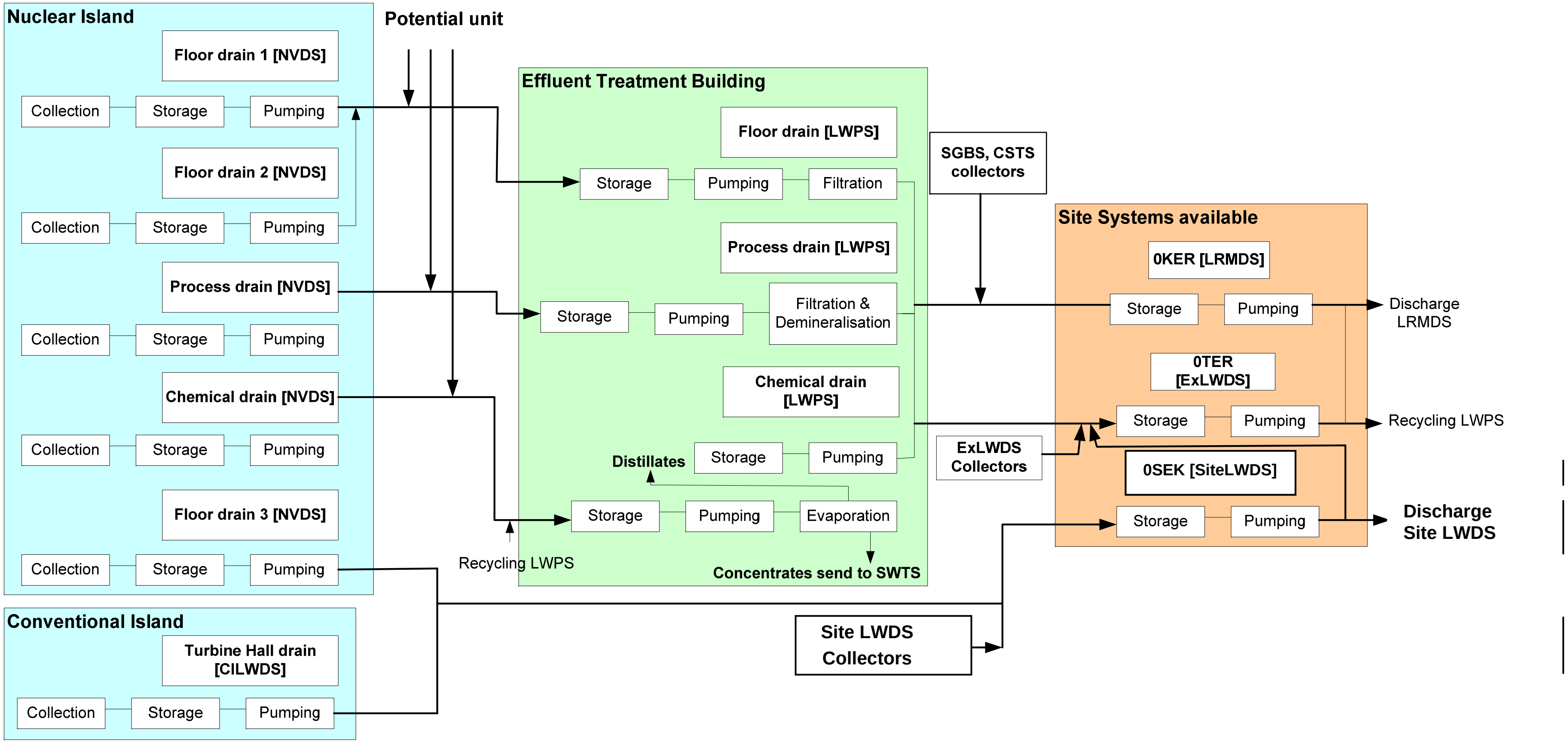
[5] Increasing due to safety requirements for the choice of continuous nitrogen flushing of the tank ullages and head spaces (TEG [GWPS]) in order to mitigate the hydrogen risk.

Sub-chapter 8.2 - Table 2: Environmental performances of the EPR compared to Sizewell B performances

	Radionuclide	**SZB values as reported in [Ref-1]**	**SZB Limits**	**EPR expected performance without contingency**	**EPR maximum discharge expected**	**SZB limit normalised to 1000 MW(e) [Ref-2]**	**EPR maximum discharge expected normalised to 1000 MW(e) [Ref-2]**
Liquid discharge	Iodine isotopes	37 GBq y^{-1} average up to 67 GBq y^{-1} (including Cs-137)	130 GBq y^{-1} for all radionuclides (excluding tritium and Cs-137)	7 MBq y^{-1}	50 MBq y^{-1}	109 GBq y^{-1}	6 GBq y^{-1}
	FP/AP			0.6 GBq y^{-1}	10 GBq y^{-1}		
	Cs-137	5 GBq y^{-1} average, up to 13 GBq y^{-1}	20 GBq y^{-1}				
	H-3	49 TBq y^{-1} average, up to 78 TBq y^{-1}	80 TBq y^{-1}	52 TBq y^{-1}	75 TBq y^{-1}	67.23 TBq y^{-1}	43.23 TBq y^{-1}
	C-14	N/A	N/A	23 GBq y^{-1}	95 GBq y^{-1}	N/A	N/A
Gaseous Discharge	Nobles gas	7 TBq y^{-1} average (but up to 17 TBq y^{-1})	300 TBq y^{-1} before 2005, 30 TBq y^{-1} proposed after 2005	0.8 TBq y^{-1}	22.5 TBq y^{-1}	25.2 TBq y^{-1}	12.97 TBq y^{-1}
	FP/AP	3 to 20 MBq y^{-1}	10 GBq y^{-1} (prior 2005), 100 MBq y^{-1} after 2005	4 MBq y^{-1}	120 MBq y^{-1}	0.08 GBq y^{-1}	0.2 GBq y^{-1}
	Iodine isotopes	450 MBq y^{-1} average, up to 2.5 GBq y^{-1}	3 GBq y^{-1} (before 2005)	50 MBq y^{-1}	400 MBq y^{-1}	0.42 GBq y^{-1}	0.23 GBq y^{-1}
	I-131	Not estimated before 2005	500 MBq y^{-1} (after 2005)				
	H-3	0.8 TBq y^{-1} average, up to 1.9 TBq y^{-1}	3 TBq y^{-1}	0.5 TBq y^{-1}	3 TBq y^{-1}	2.52 TBq y^{-1}	1.73 TBq y^{-1}
	C-14	170 GBq y^{-1} average, up to 320 GBq y^{-1}	500 GBq y^{-1} (proposed in 2005)	350 GBq y^{-1}	700 GBq y^{-1}	420 GBq y^{-1}	405 GBq y^{-1}

Sub-chapter 8.2 - Figure 1: Overall diagram for the treatment of non-recycled liquid effluents (example of Flamanville site)



SUB-CHAPTER 8.2 – REFERENCES

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2. EPR: AN EVOLUTIONARY DESIGN

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3. DESCRIPTION OF MAJOR OPTIMISATION MEASURES

3.2. SOLID RADIOACTIVE WASTE AND SPENT FUEL

3.2.2. Solid radioactive waste

3.2.2.2. Technological waste

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3.3.1 Reduction of effluents source term

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4. EVALUATION OF THE EXPECTED PERFORMANCE AND MAXIMUM DISCHARGES AND BENCHMARKING AGAINST EXISTING UNITS

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4.2. BENCHMARKING OF EXPECTED LIQUID AND GASEOUS RADIOACTIVE DISCHARGE VALUES FOR EPR

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4.2.1.1. Radioactive discharges excluding Tritium and Carbon-14

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4.2.2.4. Conclusion: gaseous discharges

[Ref-1] Effluent release options from nuclear installations. Technical background and regulatory aspects. OECD. 2003. (E)

6. REDUCING THE FRESHWATER CONSUMPTION

[Ref-1] Effluent release options from nuclear installations. Technical background and regulatory aspects. OECD. 2003. (E)

SUB-CHAPTER 8.2 - TABLE 2

[Ref-1] Statutory Guidance on the Regulation of Radioactive Discharges into the Environment from Nuclear-Licensed Sites, Consultation Paper. Department of the Environment, Transport and the Regions (DETR). London, 2000. (E)

[Ref-2] Combined methods for liquid radioactive waste treatment – final report of a co-ordinated research project 1997-2001. IAEA-TECDOC-1336. IAEA. 2003. (E)

SUB-CHAPTER 8.3 – APPLICATION OF BAT STANDARDS AND GOOD PRACTICES IN THE DESIGN

The information presented in this sub-chapter is in direct response to the requirements 1.5 and 3.2 of the Environment Agency (EA) Process and Information (P&I) Document [Ref-1].

The purpose of this sub-chapter is to demonstrate that the EPR design is based on Best Available Techniques (BAT) standards and good practices.

In particular, the successful implementation of BAT standards and good practices relies on the existence of an approved management system that covers several aspects (see section 1 of this sub-chapter, Chapter 2 of the PCER), including:

- reduction of environmental impacts;
- staff training and competency; and
- sustainability.

In addition, within the context of the demonstration of compliance with BAT, this sub-chapter provides information on waste streams:

- The effluent treatment systems for the radioactive stream will comply with relevant safety classifications which in turn include discharge control aspects (see section 2 of this sub-chapter). This classification is based on approved international standards.
- A description is provided on how non radioactive liquid waste streams will be managed and disposed of during the lifetime of the facility. Information on design considerations to minimise the potential for any fugitive emissions to groundwater is provided. This demonstration is consistent with the requirements of several regulations including Pollution Prevention and Control (PPC) Regulations 2000 [Ref-2], H1 Guidance [Ref-3], Water Resources Act 1991 [Ref-4] and the Groundwater Regulations [Ref-5].

1. MANAGEMENT SYSTEM

The concept of BAT has been defined in the EC Directive 96/61 [Ref-1] and the PPC Regulations 2000 [Ref-2] as the "*most effective and advanced stage in the development of activities and their methods of operation which indicates the practicable suitability of particular techniques for providing in principle the basis for emissions limit values designed to prevent, and where that is not practicable, generally to reduce the emissions and the impact on the environment as a whole*". In particular, this definition implies that BAT not only covers the technology utilised but also the way in which an installation is operated, to ensure a high level of environmental protection. This includes the implementation of effective management systems, and of suitable levels of management and engineering control that minimise, as far as practicable, the release of radioactivity to the environment whilst taking account of a wider range of factors, including cost-effectiveness, technological status, operational safety, and social and environmental factors.

Three principles are to be addressed at the generic design stage in order to comply with the BAT requirements, specifically:

- *Establishing and Sustaining Leadership and Management*. This principle requires that effective leadership and environmental management is available from all organisations whose activities can potentially be harmful to people or the environment;

- *High Standards of Environment Protection*. This principle requires that all management teams of an organisation focus on achieving and sustaining high standards of environment protection; and

- *Capability*. This principle requires that capabilities should be available within an organisation to secure and maintain proper protection of both people and the environment.

Chapter 2 of the present PCER describes the Quality and Project Management aspects of the project undertaken by EDF and AREVA and their subcontractors. This sub-chapter summarises those policies and practices to be implemented to ensure compliance with the above principles.

1.1. ESTABLISHING AND SUSTAINING LEADERSHIP AND MANAGEMENT

All the organisations involved in the UK EPR project are strongly committed to developing and maintaining a focus on good environmental practices, to ensure that their activities do not adversely affect people or the environment. In particular, all the organisations are aware of their environmental responsibilities, and leaders and managers are periodically trained and reminded of the potential environmental effects of their team’s activities. Strong emphasis is also placed on the development of capabilities and the decision-making process associated with the activities carried out by the UK EPR teams and partners.

At the Generic Design Assessment (GDA) stage, Management Systems are in place in each of the partners’ organisations, as demonstrated in Chapter 2 of the PCER. Teams have been set up to ensure that Management Systems are adequately established, documented, maintained and continually improved. In addition, certification by certified bodies provides strong evidence of the compliance of the partners’ organisations and activities with international laws, regulations and best practices. In particular, EDF, AREVA and AMEC all hold the ISO Standard 9001: 2008 Quality Management Systems - Requirements accreditation, and the ISO Standard 14001: 2004 (Environmental Management Systems – Requirements with guidance for use) certification. These certifications, along with measures in place such as Quality and Environment Procedures, contribute to ensure that the practices of the organisations support compliance with BAT requirements.

At the site specific and operational phases of the EPR, implementing an ISO 14001 certified management system to cover all aspects of the construction and operation (including maintenance) of the plant will significantly contribute to the reduction in impact upon the environment. The management systems in place will ensure that appropriate procedures and plans are suitable and cover areas such as organisation, operations and maintenance or competence and training.

During the operational phase, audits will be regularly conducted to check that all activities are being carried out in accordance with the set requirements. In addition, periodical reports on environmental performance, objectives and targets and future planned improvements may be published together with environmental statements. A clear and logical system for keeping records of data such as policies, roles and responsibilities, targets, procedures, results of audits or results of reviews will also be in place.

1.2. HIGH STANDARDS OF ENVIRONMENTAL PROTECTION

Environmental protection is a primary focus of the organisations involved in the UK EPR project. Managers at all levels are encouraged to develop strategies, policies, plans, systems, goals and standards for environmental protection and to ensure that these are applied throughout the whole organisation. A representative of each of the co-applicant organisations is assigned to a team for the implementation and maintenance of the Management System. Certification of the management systems by an internationally recognised body such as ISO 14001: 2004, received by EDF, AREVA and AMEC, provides the framework for the development and implementation of an effective, integrated management system.

In the co-applicant organisations involved in the project, all operations are carried out according to Health, Safety and Environment (HSE) requirements, and any operations which may pose a risk to the environment are challenged. Procedures are in place in order to ensure that good practices are used, and that environmental protection is at the heart of the organisations' concerns.

In addition, commitment to environmental protection constitutes the basis of, and is demonstrated throughout, all the activities, whether desk- or site-based. This is demonstrated by strong relationships with the regulators, stakeholders and the general public. In addition, emphasis is given to training on health, safety and environmental protection.

At the site specific and during the construction and operational phases of the project, all organisations involved will be committed to continual improvement and the prevention of pollution. In addition, compliance to the relevant legislation and to other requirements to which the organisation subscribes will be amongst the main focuses, along with a periodic review of the environmental objectives and key performance indicators. Documented procedures will be in place for the control of operations that may have an adverse effect on the environment and for the monitoring of emissions or impact, along with a preventative maintenance programme covering all plants whose failure may lead to impact on the environment.

The high standards of environmental protection maintained by the relevant organisations help ensure compliance with the BAT requirements.

1.3. CAPABILITIES

To meet their commitment for strong environmental management and leadership, the co-applicant organisations are proactive in the assessment of their resources and ensure that adequate capabilities are available to secure and maintain proper protection of people and the environment. In particular, all the organisations involved ensure that suitably qualified and experienced people are used in all parts of the projects, whether project management or technical work. This is also true for subcontractors. In order to ensure that adequate information is available to the suitably qualified and experienced people carrying out the work, document control processes and traceability of all submissions and supporting documents is also implemented. This is in particular the case for all documents relating to environmental protection.

In addition, processes are in place for the continual assessment of potential needs for resources or skills within the organisations. This is carried out by the various departments concerned, along with human resources services. Yearly one-to-one assessments are held between staff members of each organisation and their line managers, in order to assess potential training needs (whether technical, managerial or behavioural) and ensure that all individuals can access the right tools, resources and training in order to carry out their work in a manner protective of the environment.

During the site specific and operational phase, training systems should be implemented for all relevant staff to cover:

- Awareness of the regulatory implications of the Permit for the activity and their work activities;
- Awareness of all potential environmental effects from operation under normal or abnormal circumstances;
- Awareness of the need to report deviation from the Permit; and
- Prevention of accidental emissions and action to be taken when accidental emissions occur.

The skills and competencies necessary for key posts will be documented and records of training needs and training received maintained.

1.4. CONCLUSION ON MANAGEMENT SYSTEMS

All organisations involved in the UK EPR project, whether EDF, AREVA, AMEC or any other subcontractor are strongly committed to the protection of the environment and people. This, in particular, is demonstrated by the availability within all organisations of Management Systems and the commitment of managers at all levels to environmental protection. In addition, BAT is applied across radioactive and non radioactive discharges and impacts. These include all the environmental aspects and impacts described in the EA's own Horizontal Guidance Note H1 [Ref-1], covering emissions to air, emissions to water, impacts on land (direct and indirect), emissions to surface water, noise, visual impacts, odour, ozone creation potential, global warming potential, disposal of waste. Overall, the availability of suitably qualified, experienced, knowledgeable and dedicated staff provides evidence that all organisations are adequately focused and proactive in maintaining protection of people and the environment.

2. PRINCIPLES RELATING TO SAFETY STANDARDS CLASSIFICATION

2.1. SAFETY CLASSIFICATION AND THE ASSOCIATED REQUIREMENTS

As mentioned in Chapter 3 of the PCSR, EPR uses two main classification systems: the mechanical classification addresses the pressure barrier role of mechanical components (static approach) and the functional classification addresses the performance of systems required during fault transients (dynamic approach).

Both mechanical and functional classifications have evolved from the initial approach used on early Pressurised Water Reactor (PWR) designs. Through the mechanical classification, the barrier approach has been extended to cover the concept of activity retention. The functional classification has been adapted to address the long-term phase of accident analyses, and extended to cover beyond design basis and severe accident analyses.

The following aspects must be taken into account in the classification:

- The functional aspects which ensure that the safety functions can be carried out; and

- Mechanical aspects which ensure the integrity of equipment that helps protect the environment and ensure the appropriate mechanical design of equipment with an important safety duty.

It should be noted that the general requirements applicable to equipments fulfilling safety functions and/or mechanical classification are the following:

- use of design codes;
- quality assurance; and
- seismic qualification.

Other requirements are specific to functional classifications.

2.2. EFFLUENT AND WASTE TREATMENT SYSTEMS CLASSIFICATION

Radioactive waste management systems contribute to collection, containment, treatment, measurement and control of solid, liquid and gaseous radioactive discharges to the environment, during normal operation and fault conditions.

For instance, some of the systems concerned are:

- The Nuclear Vent and Drain System (RPE [NVDS]) which selectively collects all the liquid or gaseous waste produced inside and outside the containment and channels it to the associated storage and treatment plants. As a consequence this system contributes towards compliance with radioactivity criteria for liquid and gaseous discharges;
- The Coolant Storage and Treatment System (TEP [CSTS]) which enables storage, control and treatment of hydrogenated primary liquid waste. The wastes produced (distillates and concentrates) are recycled in the primary coolant system to reduce the amount of radioactive waste discharge. It is also used to treat aerated waste produced when the primary system is opened or drained; and
- The Gaseous Waste Processing System (TEG [GWPS]) which contains, treats and enables decay of hydrogenated and aerated gaseous waste derived from treatment of primary coolant or from the gas blanket of primary coolant tanks. Purification of excess gaseous waste produced during plant transients (start-up, shutdown, primary oxygenation) is carried out in series-mounted activated charcoal beds.

Details of safety classification for each of the systems are given in Chapter 3 of the PCSR.

Thus it can be seen that one aspect of the safety classification of the EPR ensures a high level of environmental protection during normal operation and fault conditions due to the associated requirements. Therefore, applying safety classification contributes to demonstrating that the installation is operating using the BAT.

3. PREVENTING FUGITIVE EMISSIONS TO SURFACE WATER, SEWERS AND GROUNDWATER

There are no planned discharges directly to the ground from the UK EPR (e.g. soak-away systems). Therefore this assessment addresses the impact of unplanned discharges only, as a result of accidents such as spillages.

Unplanned discharges may potentially arise from one or more of the following auxiliary processes:

- liquid radioactive effluent treatment and storage;
- seawater demineralisation;
- seawater chlorination or sodium hypochlorite production;
- water purification;
- foul sewage treatment;
- Turbine Hall maintenance and processes;
- oil storage (fuel storage for diesels); and
- electrical and transformer maintenance and operation.

Structures plant and machinery dealing with all operations, including radioactive waste management and handling, will be built according to strict building control standards, PPC Regulations and other relevant UK and European standards, using BAT and ensuring that the plant is able to operate during normal operations and design basis faults. Plant design and redundancy are provided in accordance with the functional requirements and the safety and environmental protection role they must provide. This includes protection against internal and external hazards identified in the safety case. All such safety and environmental equipment is recorded in the engineering and plant maintenance schedules to ensure that inspection and maintenance is carried out and recorded according to a recognised rolling programme of work (maintenance, inspection and testing schedule). This covers in particular radioactive effluent treatment systems.

In order to prevent fugitive emissions of chemicals and liquid discharges which could impact on land quality, the following measures may be implemented:

- measures for subsurface structures;
- measures for surfaces upon which materials are stored or used;
- measures for aboveground tanks (including oil tanks);
- measures for sumps and pipe runs below the local floor levels in a building; and
- measures for all other forms of storage.

Site-specific detailed design studies and future licensees will comply with EA requirements for control of emissions to water (surface water, sewer and groundwater) in particular to EA Guidance [Ref-1].

3.1. PREVENTION OF CONTAMINATION

Several levels of preventive measures are implemented in the design in order to achieve the containment of radioactive and dangerous substances.

3.1.1. Design and construction

Metallic components are manufactured and installed to ensure that they remain leak-tight over the lifetime of the facility; the systems and their main mechanical components are listed in PCSR Sub-chapter 3.2 - section 7 and Table 1.

In order to prevent any contamination from the pools and the concrete tanks, a system is designed and implemented for detecting, locating and draining leaks. This system is installed next to the welds, on the inside wall of the leak-tight metallic liner. It consists of a mesh of channels installed along the anchoring point mesh of the liner, on the vertical wall and on the bottom of the pool.

Moreover, in order to reduce the risk of overflow, the concrete tanks are built bigger than functionally required.

The buildings are erected on a concrete raft, with coating of the floors of those rooms which are identified as being potentially flooded, and part of their walls.

Pipes transferring radioactive liquids between buildings and/or effluent storage tanks and / or to the discharge ponds are installed inside leak-tight concrete galleries, which allow the collection of any leak and can be inspected periodically.

Isolation valves are also implemented along the circuits to allow the isolation of sections.

3.1.2. Collection and detection of potential leak

Leaks are collected through the RPE [NVDS] piping and sumps system in the nuclear island and through Conventional Island Liquid Waste Discharge System (SEK [CILWDS]) in the Turbine Hall. More information on the RPE [NVDS] functions and design is available in PCER Sub-chapter 6.4 - section 2.1. The operator is warned of massive liquid inlet in any RPE [NVDS] sump, by the means of the alarms associated with the RPE [NVDS] sumps level measurement sensors. An alarm is also given in case of an excessive sump pump run time, which can indicate a continuous inflow of liquid in the sump.

Part of the effluent recovery system is embedded in the raft concrete: in order to prevent any leak through the concrete, there are successively a floor drain, a double wall drain, and a sump. Effluents that are collected in the inner drain are taken to the slump liner. A special receptacle recovers any leaks from the inner drain collected by the outer sleeve and visual inspection to detect any leakage between the two liners is performed using a tube.

Sumps are also fitted with visual inspection tubes so that any leakage from the liner can be seen.

3.1.3. Monitoring during the plant operation

There are inspections of the equipments during maintenance.

The PCER Sub-chapter 12.6 presents in details the monitoring of groundwater. A site specific environmental protection and monitoring programme will be established to monitor the environment around the UK EPR site according to the relevant requirements. During the preparatory construction phase, a network of piezometers will be placed around the site. Groundwater samples will be collected from the piezometers in order to monitor the groundwater quality and to detect any contaminants that inadvertently reach the groundwater. If spills or accidental releases occur, this monitoring system will allow the detection of the contaminants in the groundwater before they migrate offsite. A network of piezometers will remain in place during the operational phase of the EPR.

4. TECHNIQUES AND GOOD PRACTICES TO REDUCE ENVIRONMENTAL IMPACTS

4.1. TECHNIQUES AND GOOD PRACTICES

As a minimum, the techniques and good practices employed to reduce the impacts of the EPR will be compliant with EA requirements and suitable guidance notes.

4.2. EFFECTIVE MANAGEMENT OF WASTES

Suitable and appropriate waste storage and handling arrangements will be implemented at the UK EPR, which as a minimum may include:

- Providing suitable storage areas for wastes which will minimise or prevent leaks and spills from contaminating the ground;

- Storage vessels for liquids will be specified for a ‘suitable life’ to appropriate British Standards and Eurocodes. Storage tanks will be individually bunded or where this is not possible, storage areas for a number of tanks will be bunded in accordance with current UK pollution prevention standards; and

- Wherever possible, non radioactive waste will be source segregated and treated to maximise recycling and recovery, thus minimising the quantity of waste destined for disposal, e.g. paper, cardboard and textiles may be compacted to facilitate recovery.

Detailed life cycle checks will be carried out from source to fate of wastes to ensure waste arising at the UK EPR is effectively managed in order to minimise impact on the environment.

4.3. BEST AVAILABLE TECHNIQUES TO MINIMISE OTHER ENVIRONMENTAL IMPACTS

The EPR incorporates a full and extensive suite of plant and systems for the protection of the environment and all incorporate design principles in accordance with BAT. The following are brief examples in terms of environmental impacts listed in the EA Guidance Note H1 [Ref-1]:

- Noise: For example, diesel generators are fitted with silencers;

- Visual impacts: The immediate environs will be designed to facilitate visual amenity and minimise off site visual impacts;
- Odour is not expected to be a significant impact at any time during normal operation. Odour due to occasional testing of the diesel sets may occur;
- Ozone creation potential: No significant impacts are expected from handling chemicals; and
- Global warming potential: The EPR will overall reduce emissions of carbon dioxide gas, a source of global warming potential.

These are very brief examples of how impacts have been addressed and minimised in accordance with BAT at all stages in the design and for all plant items and systems associated with the EPR site.

5. CONCLUSION

It has been demonstrated that applying safety classification and thus ensuring a high level of environment protection contribute to the EPR operating using BAT. In addition BAT is applied on the minimisation of radioactive and non radioactive discharges and impacts. These include all the environmental aspects and impacts described in the EA Horizontal Guidance Note H1 [Ref-1], covering:

- emissions to air;
- emissions to water;
- impacts on land (direct and indirect);
- emissions to surface water;
- noise;
- visual impacts;
- odour;
- ozone creation potential;
- global warming potential; and
- disposal of waste.

SUB-CHAPTER 8.3 – REFERENCES

External references are identified within this sub-chapter by the text [Ref-1], [Ref-2], etc at the appropriate point within the sub-chapter. These references are listed here under the heading of the section or sub-section in which they are quoted.

[Ref-1] Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs. The Environment Agency. January 2007. (E)

[Ref-2] Pollution Prevention and Control Regulations 2000. SI No. 1973. The Stationery Office Ltd. ISBN 978-011099621-9.

[Ref-3] Integrated Pollution Prevention and Control (IPPC) – Environmental Assessment and Appraisal of BAT. Horizontal Guidance Note IPPC H1. Environment Agency & Environment and Heritage Service & Scottish Environment Protection Agency. July 2003. (E)

[Ref-4] Water Resources Act 1991. ISBN 978-0105457916. The Stationery Office Ltd. (E)

[Ref-5] Groundwater Regulations 1998. SI No. 2746. The Stationery Office Ltd. ISBN 978-011079799X. (E)

1. MANAGEMENT SYSTEM

[Ref-1] European Community Directive 96/61/EC, Integrated Pollution Prevention and Control. 1996. (E)

[Ref-2] Pollution Prevention and Control Regulations 2000. SI No. 1973. The Stationery Office Ltd. ISBN 978-011099621-9. (E)

1.4. CONCLUSION ON MANAGEMENT SYSTEMS

[Ref-1] Integrated Pollution Prevention and Control (IPPC) – Environmental Assessment and Appraisal of BAT. Horizontal Guidance Note IPPC H1. Environment Agency & Environment and Heritage Service & Scottish Environment Protection Agency. July 2003. (E)

3. PREVENTING FUGITIVE EMISSIONS TO SURFACE WATER, SEWERS AND GROUNDWATER

[Ref-1] Guidance for the Recovery and Disposal of Hazardous and Non Hazardous Waste, Sector Guidance Note IPPC S5.06. Issue 4. Environment Agency & Environment and Heritage Service. 2004. (E)

4. TECHNIQUES AND GOOD PRACTICES TO REDUCE ENVIRONMENTAL IMPACTS

4.3. BEST AVAILABLE TECHNIQUES TO MINIMISE OTHER ENVIRONMENTAL IMPACTS

[Ref-1] Integrated Pollution Prevention and Control (IPPC) – Environmental Assessment and Appraisal of BAT. Horizontal Guidance Note IPPC H1. Environment Agency & Environment and Heritage Service & Scottish Environment Protection Agency. July 2003. (E)

5. CONCLUSION

[Ref-1] Integrated Pollution Prevention and Control (IPPC) – Environmental Assessment and Appraisal of BAT. Horizontal Guidance Note IPPC H1. Environment Agency & Environment and Heritage Service & Scottish Environment Protection Agency. July 2003. (E)

SUB-CHAPTER 8.4 – IMPLEMENTATION OF BAT WITHIN MONITORING PROCEDURES

LIST OF TABLES

1. INTRODUCTION

This sub-chapter deals with a part of requirement 2.6, of the Environment Agency (EA) Process and Information (P&I) Document [Ref-1], i.e. justification that the monitoring implemented for the UK EPR radioactive discharges represents the Best Available Techniques (BAT) (other parts of requirement 2.6 being discussed in Chapter 7 of the PCER). The sub-chapter also deals partially with requirements 3.2 and 3.3 (non radioactive discharges).

To make sure that statutory requirements are answered, the plant operator implements a discharge and environmental monitoring programme as part of normal operations.

Operation of the EPR will be supported by an Environmental Monitoring Programme (see Chapter 12 of the PCER). This will be agreed with the relevant regulatory authority and will cover a suitable range of environmental media, including food crops and other agricultural produce relevant to the identified critical groups in the region. The samples will be collected from a range of locations around the plant. Samples will be analysed by suitable accredited methods for a range of nuclides to be agreed at a later date.

The sub-chapter presents a selection of measures for ensuring an optimum level of discharge monitoring in normal operation, including explanation and justification of methods, sampling arrangements, techniques and systems used to measure discharges.

The monitoring programme provided is indicative as the final monitoring programme will be the responsibility of the plant operator and will be risk based and prepared and agreed with the EA prior to operation. The programmes will be managed under the overall Environmental Management System.

In agreement with the EA Technical Guidance Notes on Monitoring: M11 (Monitoring of radioactive discharges to atmosphere) [Ref-2], M12 (Monitoring of radioactive discharges to Water from Nuclear Facilities) [Ref-3] and M18 (Monitoring of discharges to water and sewer) [Ref-4], the plant operator implements a documented Quality Management System which covers all aspects of sampling and analysis of discharges based on the requirements of proven international standards.

The monitoring procedures take into account the experience acquired from previous work in this field. This allows for an optimised monitoring system to be proposed based on the most relevant practices and data. The techniques of assessment are kept under review to take account of experience and technical developments and to ensure that the BAT are used to maximise assessment accuracy, provided that they are cost effective.

As described above this sub-chapter deals with discharge arrangements. In-process sampling and analysis are broken into the main plant areas (see PCSR):

- Primary circuit: This may have on-line sampling and grab sampling. It will measure chemical parameters (pH, lithium (Li), boron (B), etc.) and fission products in the primary coolant for normal operation and faults. This is BAT as it ensures early warning of primary coolant contamination, by failed fuel for example;
- Radwaste systems (in-process): There will be sampling systems for solid wastes (see Sub-chapter 8.2) and at intermediate points in liquid and gaseous systems prior to discharge points, especially to detect leaks;

- Secondary (steam) system: Equipment to detect primary to secondary steam generator tube leakages, leakages between secondary and condenser; and
- Systems to detect activity in different plant areas, especially in the reactor containment and active areas.

All these systems will give local plant indications and where critical, indications in the Main Control Room (MCR) as well.

2. MONITORING PROGRAMME OF GASEOUS RADIOACTIVE DISCHARGES

2.1. RADIOACTIVE GASEOUS DISCHARGES SPECTRA

As described in Chapter 7 of the PCER, five categories of gaseous radionuclides are subjected to discharge limits:

- tritium;
- iodine isotopes: iodine-131 (I-131) and iodine-133 (I-133);
- carbon-14 (C-14);
- noble gases: argon-41 (Ar-41), krypton-85 (Kr-85), xenon-131m (Xe-131m), xenon-133 (Xe-133), xenon-135 (Xe-135);
- the other beta or gamma emitting activation or fission products: cobalt-58 (Co-58), cobalt-60 (Co-60), caesium-134 (Cs-134) and caesium-137 (Cs-137).

This evolving reference spectra is based on experience feedback from the analyses carried out in the French Nuclear Power Plants (NPPs).

These radionuclides are identified both in the EA Guidance for monitoring M11 [Ref-1] (monitoring of radioactive discharges to atmosphere) and in EU Commission Recommendation 2004/2/Euratom [Ref-2]. In addition, it should be noted that the gaseous discharges spectra is the same list of nuclides as measured in gaseous discharges from Sizewell B (SZB) Pressurised Water Reactor (PWR) (see section 6 of this sub-chapter).

2.2. GASEOUS RADIOACTIVE DISCHARGE PROCEDURES

All of the gaseous discharges via the stack are subjected to the following analyses at a periodicity to be agreed with the Regulators:

- flow rate measurement in the stack (duplicated and recorded measurement);
- gross beta activity measurement in the stack (duplicated and recorded measurement);
- tritium activity measurement (duplicated and recorded measurement);

- analysis of noble gases;
- gross gamma activity measurement and analysis of iodine isotopes;
- check of the absence of gross alpha activity, gross beta activity measurement and analysis of the other activation or fission products; and
- carbon-14 activity measurement in the stack (duplicated and recorded measurement).

These analyses allow the discharge activity to be established and the emission rates from the stack to be determined, and therefore ensure that the activities and emission rates are below the defined limits.

2.3. SAMPLING AND MEASUREMENT TECHNIQUES

2.3.1. Tritium

The monitoring of tritium involves:

- continuous sampling (bubbler) and laboratory analysis; and
- double sampling devices at the stack (same devices), including an emergency power supply.

Tritiated water vapour is trapped by a refrigerated bubbler. The bubbler draws the sampled air through a meter that records the volume of air sampled.

Tritiated water vapour is then trapped in two bottles through which the sampled air flows. After a period of time, tritiated water is measured in the laboratory by liquid scintillation counting.

The quantity of tritium measured is then related to the overall air volume sampled.

2.3.2. Carbon-14 measurement

The analysis of carbon-14 involves:

- continuous sampling (catalytic furnace and molecular sieves) and laboratory analysis; and
- double sampling devices at the stack (same devices), including an emergency power supply.

The measurement method of carbon-14 in gaseous effluents has been adapted from previous experience at German NPPs. A sampling machine, located in the stack, burns the carbon-14 into carbon dioxide in a catalytic furnace and traps the carbon-14 in a cartridge filled with molecular sieves (the molecular sieve only traps carbon as carbon dioxide). After a 3-months sampling period, the cartridge is analysed in the laboratory. The molecular sieve is first desorbed by heating at 450°C. After chemical transformations, carbon-14 is then measured by liquid scintillation counting. The detection limit of the method is very low.

In France, measurements of carbon-14 began at St. Laurent nuclear power plant in 1999, and have since been implemented at all French NPPs.

2.3.3. Iodine isotopes/Particulates

The analysis of iodine isotopes involves:

- continuous sampling (on paper filter and charcoal cartridge) and laboratory analysis;
- double sampling devices at the stack (same devices), including an emergency power supply; and
- sampling lines for iodine isotopes and particulates.

The paper filter and the charcoal cartridge of the above device are respectively used for the continuous sampling of particulates and halogens present in molecular and organic form.

Samples are drawn from the discharge stack.

The deposited activity on each filter (for collecting airbornes) and charcoal cartridge (for collecting gaseous iodine isotopes) is analysed in the laboratory by gamma spectrometry. Specific qualitative and quantitative tests enable the identification of the trapped isotopes.

2.3.4. Noble gases

Measurements taken at the discharge stack enable continuous monitoring of noble gas discharges (high and low activity).

A specific device records continuous noble gas volumetric activity measurements. A sample is drawn from the discharge stack. It is then admitted into a shielded vessel for detection (gamma spectrometry). The monitor displays the measured volumetric activity and provides visual and audible indications whenever the pre-set alarm thresholds levels are exceeded.

Moreover, the UK EPR will be equipped to enable gas measurement (maybe an on-line gamma spectrometer) downstream the Gaseous Waste Processing System (TEG [GWPS]) delay beds. This notably enables measurement of noble gases derived from TEG [GWPS].

3. MONITORING PROGRAMME OF LIQUID RADIOACTIVE DISCHARGES

3.1. RADIOACTIVE LIQUID DISCHARGES SPECTRA

As described in Chapter 7 of the PCER, four categories of liquid radionuclides are subjected to discharge limits: tritium, carbon-14, iodine isotopes, and the other beta or gamma emitting activation or fission products.

- tritium;
- carbon-14;
- iodine isotopes: I-131;

- other fission and activation materials: manganese-54 (Mn-54), cobalt-58 (Co-58), cobalt-60 (Co-60), silver-110m (Ag-110m), tellurium-123m (Te-123m), antimony-124 (Sb-124), antimony-125 (Sb-125), caesium-134 (Cs-134), caesium-137 (Cs-137).

This evolving reference spectra is based on experience feedback from the analyses carried out in the French Nuclear Power Plants. As for gaseous discharges, measurement of carbon-14 in liquid discharges in France began in 1999.

These radionuclides are identified both in the EA Guidance for monitoring M12 [Ref-1] (monitoring of radioactive discharges to water) and in EU Commission Recommendation 2004/2/Euratom [Ref-2].

3.2. SAMPLING AND MEASUREMENT PROCEDURES

Within the EPR concept, any discharge of liquid radioactive effluent into the environment is subject to prior measurement of volume and activity upstream of the discharge point in the storage tanks (T (0KER [LRMDS]), Ex (0SEK [SiteLWDS]) or S (0TER [ExLWDS])). This measurement is performed in laboratory after a representative sample of the effluent to be discharged is taken; it determines whether the effluent may be discharged into the environment and sets out discharge conditions.

Continuous sampling of discharged effluent is ensured by a flow proportional device installed on the common discharge pipeline of the T (0KER [LRMDS]) and S (0TER [ExLWDS]) tanks and on the discharge pipeline of the Ex (0SEK [SiteLWDS]) tanks.

The detailed overview of discharged activities is established by multiplying the volume activity, measured in a sample taken during discharge by the volume of effluent discharged.

On the common discharge pipeline of the T (0KER [LRMDS]) and S (0TER [ExLWDS]) tanks, a volume activity monitor control is installed. This activates an alarm in the control room and causes the automatic closure of a valve which stops the discharge in case a pre-set threshold is exceeded. .

The common discharge pipeline of the T (0KER [LRMDS]) and S (0TER [ExLWDS]) tanks is also automatically isolated on a flow rate variance.

Validation of measurements is obtained by periodic calibration of the measuring devices based on standard sources, in accordance with relevant authorisation requirements.

The measurements, calibration data and the assessment of the activities discharged are recorded and kept up-to-date by the plant operator.

4. TYPES OF ACTIVITY MEASUREMENT

The following type of activity are measured both in gaseous and liquid discharges.

Gross Alpha

Gross alpha activity measured using a proportional counter whose efficiency is defined based on an americium-241 (or plutonium-239) standard source.

Gross Beta

Gross beta activity measured using a proportional counter whose efficiency is defined based on a strontium-90 and yttrium-90 standard source.

Gross Gamma (NaI)

Activity of a mix of gamma emitting radio-nuclides measured using a sodium iodide (NaI) scintillator whose overall efficiency is defined based on metering of a caesium-137 standard source (100 keV to 2 MeV window).

Gamma spectrometry (pure Germanium – Hyper)

Identification of the different gamma radio-emitters measured using a Ge-HP detector which is calibrated using a multi-gamma standard source (50 keV to 2 MeV window).

Tritium

Measurement of the activity of tritium by liquid scintillation. The efficiency is obtained based on a Tritium standard source in the appropriate energy window.

Carbon-14

Measurement of the activity of carbon-14 by liquid scintillation.

For the measurement method of carbon-14 in liquid effluents, a standard apparatus followed by a liquid scintillation counter is used. A sample of the released tank effluent is chemically conditioned to a high pH with NaOH to avoid release of the carbon dioxide form. The purpose of the device is:

- to convert all chemical forms of carbon-14 in carbon dioxide; and
- to trap CO_2 in a specific absorbent.

The detection limit of the method is 100 Bq l^{-1} for a counting time of 30 minutes.

5. DETECTION LIMITS OF TECHNIQUES

The EU Commission Recommendation 2004/2 Euratom specifies levels of detection for measurement and assessment of discharges from nuclear facilities.

This Recommendation is addressed to European Union Member States and defines the format and content of information to be reported to the Commission on radioactive discharges into the environment from nuclear power reactors and reprocessing plants in the European Union. It provides guidance to Member States on the assessment and reporting data relating to radioactive discharges. In this way, the Commission aims to achieve a higher degree of consistency and utility of the information it receives from across the Union.

The Recommendation identifies in Annex 1 both for gaseous and liquid discharges:

- a category and a list of radionuclides; and
- key nuclides, i.e. *“suitable measurement sensitivity indicator for each radionuclide category”*.

Since detection limit are only identified for key nuclides, we will assess in the following paragraph the detection limits determined for the key nuclides for the EPR by comparison with the corresponding requirements defined in the Recommendation.

5.1. DEMONSTRATE COMPLIANCE WITH EU RECOMMENDATION

Sub-chapter 8.4 - Table 1 (gaseous discharges) and Sub-chapter 8.4 - Table 2 (liquid discharges) allow comparison of detection limits for key nuclides identified in Annex 1 of EU Commission Recommendation with the detection limits achieved by the measuring techniques on the EPR.

As reported in these tables most of the detection limits for the measuring techniques implemented for the EPR are well below the corresponding requirements found in the Recommendation. It should be noted that the measuring techniques (equipment used for sample analysis) implemented for the monitoring of EPR gaseous and liquid radioactive discharges will be capable of detecting very small levels of radioactivity. Indeed, the majority of detection limit levels are smaller than the corresponding requirements.

For the particular cases of strontium-90 (Sr-90), plutonium-239 (Pu-239) + plutonium-240 (Pu-240) and americium-241 (Am-241):

- Strontium-90 (and strontium-89 (Sr-89)) have never been analysed in the gaseous and liquid radioactive discharges from French NPP. A measurement campaign in 2006 demonstrated that this radionuclide is not released in the effluent discharges. In addition, the results of the measurement campaign are compliant with the published literature that concluded that the strontium-90 retention is related to the efficiency of the Chemical and Volume Control System (RCV [CVCS]) filters and resins.

  At Sizewell B strontium-90 is included purely for historical reasons associated with weapons fall out and could be removed from analysis, as it is not discharged.

- Alpha emitters (plutonium-239 + plutonium-240, americium-241): Based on French experience it is not proposed to seek authorisation for specific actinides discharges (both gaseous and liquid). The gross alpha activity (i.e. total alpha) measurement is only carried out to ensure that the measure is below the decision threshold mentioned in the site discharge authorisation. It should be noted that the Recommendation states that *“Total-alpha should only be reported if nuclide-specific information on alpha-emitters is not available.”*

  At Sizewell B americium-241 is neither a key radionuclide, nor has it ever been detected in the reactor coolant, much less in discharges.

Overall, it is suggested in the Sizewell B submission that reporting of strontium-90, sulphur-35 and americium-241 is not relevant to a PWR and should be discontinued.

Therefore, from inspection of Sub-chapter 8.4 - Table 1 and Sub-chapter 8.4 - Table 2, it can be concluded that the EPR uses BAT to assess discharges. The detection limits achieved for the measurements are broadly compliant with EU Recommendation and ensure that the values reported are representative of the actual discharges (having taken into account the accuracy of the sampling and analysis methods and the effect of combining these).

5.2. DECISION THRESHOLDS

EU Commission Recommendation states that:

"The determination of detection limits, decision thresholds, and the expression of results should comply with international standard ISO/IS 11929-7. For practical reasons, even though technically the decision threshold is below half the detection limit actually achieved for a measurement, the decision threshold may conservatively be taken to be equal to one half of the detection limit.

Where measurement outcomes are below the decision threshold, these outcomes should conservatively be substituted by one half of the decision threshold. However, if repeated measurement outcomes in the period considered are all below the decision threshold, then it is reasonable to assume that the true value is zero, i.e. that the radionuclide is not present in the discharge."

The EPR methodology for calculations of decision thresholds will be defined in accordance with this recommendation (see Sub-chapter 8.2).

6. COMPARISON WITH ARRANGEMENTS IN PLACE AT SIZEWELL B FOR RADIOACTIVE DISCHARGES

At Sizewell B sampling systems are provided for assessing discharges from the major outlets identified [Ref-1].

6.1. GASEOUS DISCHARGES

Sampling systems have been installed for tritium, carbon-14, halogens, noble gases and particulate material.

6.1.1. Particulate Sampling

Sampling of particulate material in discharge routes is carried out by either inserting a filter paper into the flow of discharging gas or by transferring a small portion of discharging gas down a gently curved sample pipe to a filter paper.

The filter paper is analysed for beta radioactivity using commercially available beta counting equipment.

6.1.2. Halogens Sampling

Sampling of halogens in discharge routes is carried out by transferring a portion of the gas taken for particulate sampling and passing it through charcoal that has been specially treated to make it adsorb halogens very efficiently. The halogens adsorption technique used for sampling is the same as that used for reduction of halogens in gaseous discharges.

Each discharge outlet charcoal sample is analysed for radioactive halogens using commercially available gamma spectrometry counting equipment.

6.1.3. Tritium Sampling

Sampling of tritium in discharge outlets is carried out by diverting a proportion of the discharge gas flow through a high temperature furnace and then through a glass bottle containing water, slightly acidified with nitric acid.

For each discharge outlet, the contents of the tritium ‘bubblers’ are combined and their collective volume measured. The contents are then analysed for tritium radioactivity using commercially available liquid scintillation counting equipment.

6.1.4. Carbon-14 Sampling

The tritium sampling systems described in section 6.1.3 are also used for the sampling of carbon-14. After the sample gas has passed through the second nitric acid bottle, it is passed into a glass bottle containing sodium hydroxide dissolved in water (sodium hydroxide solution). Passing the sample gas through the furnace described in section 6.1.3 and mixing it with air at a high temperature ensures that carbon-14 is fully oxidised, which then ensures that it reacts chemically with the sodium hydroxide solution.

Each sodium hydroxide ’bubbler’ sample is analysed for carbon-14 radioactivity using commercially available liquid scintillation counting equipment.

6.1.5. Noble Gas Sampling

Gas from the discharge stack is passed through a silver zeolite filter by air operated pumps. The filter is contained within a sample chamber that is constantly monitored by a sodium iodide detector.

The on-line instruments present the concentration of noble gas radioactivity in the sample gas, expressed in Bq/m^3.

6.2. LIQUID DISCHARGES

There are number of systems and components containing radioactive, or potentially radioactive, liquids that drain into one discharge route for liquid waste (the Circulating Water Surge Chamber). These are listed below:

(i) the Liquid Radioactive Waste System (LRWS);

(ii) the Secondary Liquid Waste System (SLWS);

(iii) the Steam Generator Blowdown System (SGBS);

(iv) the Wet Well; and

(v) small miscellaneous discharges that can occur via Storm Water and other Drains.

Discharges from (i) to (iii) inclusive have installed sampling systems for routine collection of a representative sample of liquid waste (a ‘flow proportional sampler’).

Sampling is carried out during each discharge by automatic systems that transfer a small portion of liquid as it is being discharged into a sample bottle. The rate of liquid discharge is measured by the sampling equipment and the quantity of liquid transferred to the bottle is adjusted according to this rate of discharge to ensure that the final sample is representative of the discharge volume.

Prior to discharge, a representative sample is taken from the tank about to be emptied to confirm that the contents are suitable for disposal.

Samples are analysed for tritium and ‘activity excluding tritium’, e.g. alpha and beta emitters excluding tritium.

It should be noted that carbon-14 in liquid radioactive discharge is not monitored separately.

6.3. CONCLUSION

The range of nuclides and methods used for analysis and the data quality objectives that will be used for the EPR are broadly consistent with those already applied on the UK's current operating PWR at Sizewell B. Several separate assessments have been carried out to show that the methods used at Sizewell over the last 20 years have ensured that short and long term trends in discharge data can be recorded and used to show the extent of compliance with the plants discharge authorisations and that short term trends have allowed full fault identification. They have also been used to support a range of dose assessments. The methods for sampling and monitoring there have therefore been consistently shown to be BAT and hence this can also be assumed for the UK EPR.

7. MONITORING PROGRAMME ASSOCIATED TO CHEMICAL DISCHARGES

7.1. EMISSIONS SPECTRA

7.1.1. Discharges from tanks

As described in Chapter 7 of the PCER, many physico-chemical parameters of the effluents from the T (0KER [LRMDS]), S (0TER [ExLWDS]) and Ex (0SEK [SiteLWDS]) tanks are analysed prior and after discharge:

- Representative one-off sampling is carried out in each tank and laboratory analyses undertaken prior to the effluents being discharged from the tank on the following substances:
    - boric acid (H_3BO_3) concentration measurement;
    - hydrazine (N_2H_4) concentration measurement;
    - morpholine (C_4H_9ON) concentration measurement; and
    - ethanolamine (C_2H_7ON) concentration measurement;
- Retrospective controls are carried out on the following:
    - morpholine (C_4H_9ON) concentration measurement;
    - ethanolamine (C_2H_7ON) concentration measurement;
    - phosphate concentration measurement (PO_4^{3-});
    - nitrogen (N) concentration measurement (measurement of the ammonium ions, nitrates and nitrites);
    - detergent concentration measurement;
    - five-day biochemical oxygen demand (BOD_5) determination;
    - chemical oxygen demand (COD) measurement;
    - total suspended solids (TSS) concentration measurement; and
    - total metals (zinc, copper, manganese, nickel, chromium, iron, aluminium, lead) concentration measurement.

7.1.2. Outfall emissions

In addition a programme is implemented to monitor any chemical discharges not associated with liquid radioactive effluents at the outfalls. It particularly allows monitoring of:

- suspended solids, sulphate and iron concentrations;

- BOD_5 determination;
- hydrocarbon concentration; and
- other additional parameters: residual oxidants, chlorine, pH and flow rate.

7.1.3. Emissions to air

Regarding the non radioactive emissions discharged into the atmosphere, monitoring of the following is carried out:

- Sulphur and nitrogen oxides discharges present in the exhaust gases from the backup electricity generator sets;
- Methanol and carbon monoxide emitted by the glass wool insulation during the initial temperature increase; and
- Ammonia as a result of the thermal decomposition of the steam generator layup solution on restarting.

As stated in Chapter 7 of the PCER, the PPC permit will specify the continuous emission monitoring and extractive test monitoring programme that is required, in accordance with the EA guidance documents M1 [Ref-1] and M2 [Ref-2].

The type of monitoring required (which can range from occasional extractive sampling to continuous emission monitoring) will be determined in accordance with this guidance and the quantities and frequency of pollutant releases. Initial assessments indicate that none of the above emissions will be continuous or substantial in quantity.

7.2. EXAMPLES OF ANALYTICAL CHEMISTRY TECHNIQUES USED

As described in Chapter 7 of the PCER, the following techniques are implemented:

- **Titration** (carried out for boric acid measurement) is a common laboratory method of quantitative/chemical analysis that can be used to determine the concentration of a known reactant. Because volume measurements play a key role in titration, it is also known as volumetric analysis;
- **Absorption spectroscopy** (carried out for boric acid, hydrazine, nitrates and nitrites, phosphate, chemical oxygen demand measurements, etc.) refers to a range of techniques employing the interaction of electromagnetic radiation with matter. In absorption spectroscopy, the intensity of a beam of light measured before and after interaction with a sample is compared;
- In analytical chemistry, **atomic absorption spectroscopy** is a technique for determining the concentration of a particular metal element in a sample. Atomic absorption spectroscopy can be used to analyse the concentration of over 62 different metals in a solution;

- **Capillary electrophoresis** (carried out for morpholine, ethanolamine, ammonium ions measurements) also known as capillary zone electrophoresis can be used to separate ionic species by their charge and frictional forces. In traditional electrophoresis, electrically charged analytes move in a conductive liquid medium under the influence of an electric field. The technique of capillary electrophoresis was designed to separate species based on their size to charge ratio in the interior of a small capillary filled with an electrolyte; and

- **Ionic chromatography (nitrites, nitrates, phosphates, sulphates).**

7.3. COMPLIANCE WITH BAT REQUIREMENTS FOR CHEMICAL DISCHARGES MONITORING AND INTERNATIONAL STANDARDS

The *Guidance for the Recovery and Disposal of Hazardous and Non Hazardous Waste* [Ref-1] describes indicative BAT requirements for emissions monitoring (to air, water and sewer).

It should be noted that the EDF and AREVA monitoring programme is compliant with these BAT requirements, in particular with the following principles:

- *“monitoring should generally be undertaken during all phases of operation;*

- *Continuous monitoring and recording (or at least sampling in the case of water) are likely to be required”*; and

- If any, monitoring and reporting of emissions to water and sewer should include at least the following parameters as *flow rate, pH, Suspended solids, COD/BOD,* etc.

Regarding the sampling and analysis standards, the guidance states that “*Standards should be selected in the order of priority as given in the IPPC Bureau's Reference Document on the General Principles of Monitoring. This order is:*

- *Comité Européen de Normalisation (CEN); and*

- *International Standardisation Organisation (ISO)”.*

And “*if the substance cannot be monitored using CEN or ISO standards then a method can be selected from any one of the following:*

- *American Society for Testing and Materials (ASTM);*

- *Association Francaise de Normalisation (AFNOR);*

- *British Standards Institution (BSI);*

- *Deutsches Institute fur Normung (DIN);*

- *United States Environmental Protection Agency (US EPA);*

- *Verein Deustcher Ingenieure (VDI)”.*

According to these recommendations and as describes in Sub-chapter 8.4 - Table 3, Sub-chapter 8.4 - Table 4, Sub-chapter 8.4 - Table 5, Sub-chapter 8.4 - Table 6, Sub-chapter 8.4 - Table 7, and Sub-chapter 8.4 - Table 8, the substances subject to a monitoring programme are monitored using CEN, ISO standards and French Standards regulated by AFNOR when they exist.

There are a number of British Standards for air quality monitoring, water quality monitoring, sampling and analysis (including monitoring, sampling and design of monitoring programmes for effluents, contaminated waters and process waters) the EPR monitoring programme of emissions substances will be consistent with these requirements.

Finally, monitoring arrangements will be consistent with the EA quality requirements, in line with the EA Monitoring Certification Scheme (MCERTS) where relevant standards and procedures exist. This scheme provides a framework within which environmental measurements and monitoring are undertaken in line with EA requirements. MCERTS currently applies to emissions to air, water and land (analysis of soil samples).

8. CONCLUSION

The Radioactive Substance Act 1993 (RSA 93) [Ref-1] requires that BAT are used in activities associated with the management of radioactive materials and wastes, including sampling, measurements, tests, surveys and calculations.

The PPC Regulations [Ref-2] were brought into force on 1st August 2000 and implement the requirements of the EU’s IPPC Directive (96/61/EC). The Directive sets out the principle that industrial operators are responsible for undertaking monitoring of emissions from the installation.

This sub-chapter demonstrates that:

- The EPR’s monitoring arrangements are sufficient and adequate;
- The EPR’s monitoring procedures are consistent with EU requirements [Ref-3] and EA Guidance Notes; and
- The BAT has been taken into account in the activities related to monitoring.

Therefore, it is concluded that the EPR uses BAT for monitoring activity in the primary coolant and other process systems to ensure compliance with normal operating envelope and early detection of faults within the plant. Other systems ensure sampling and analysis in all downstream systems and in the radioactive treatment plants (for liquids, gases and solids). Finally, sampling and analysis systems are supplied on the discharge points to ensure compliance with limits and authorisations and demonstration to the EA that discharges to the environment are minimised as low as possible and that any excursions in these due to faults can be detected early and appropriate actions taken.

The range of nuclides and detection limits are in compliance with EU recommendations and expected nuclide patterns from other PWR plant.

Sub-chapter 8.4 - Table 1: Gaseous discharges - Detection limits for measurement techniques used - compliance with the EU Recommendations

Key nuclides (for LWR)	EU Recommendation requirement for the detection limit (Bq m^{-3})	Detection limits for the measurement techniques used – EPR (Bq m^{-3})
Kr-85	1×10^{4}	2.5×10^{4}
Co-60	1×10^{-2}	2×10^{-3}
Sr-90	2×10^{-2}	N/A
Cs-137	3×10^{-2}	2×10^{-3} Co-60 equivalent
Pu-239 + Pu-240	5×10^{-3}	N/A
Am-241	5×10^{-3}	N/A
Alpha total	1×10^{-2}	2×10^{-3}
I-131	2×10^{-2}	2×10^{-3}
H-3	1×10^{3}	4×10^{1}
C-14	1×10^{1}	2×10^{1}

Sub-chapter 8.4 - Table 2: Liquid discharges - Detection limits for measurement techniques used - compliance with the EU Recommendation

Key nuclides (for LWR)	EU Recommendation requirement for the detection limit (Bq m^{-3})	Detection limits for the measurement techniques used – EPR (Bq m^{-3})
Co-60	1×10^4	5×10^3 for T (0KER [LRMDS]) tanks measurements 2×10^3 for Ex (0SEK [SiteLWDS]) tanks measurements
Sr-90	1×10^3	N/A
Cs-137	1×10^4	5×10^3 Co-60 equivalent
Pu-239 + Pu-240	6×10^3	N/A
Am-241	5×10^1	N/A
Alpha total	1×10^3	1×10^3
H-3	1×10^5	2×10^5

Sub-chapter 8.4 - Table 3: Reference standards[1] of measurement techniques used for measuring chemical substances associated with liquid radioactive effluents

Parameters		Measurement method	Method's quantification limit (mg l^{-1})	Reference standard
Boric acid (H_3BO_3)		Titration	50 in boron	No existing standard
		Inductively Coupled Plasma (ICP)	0.005	NF EN ISO 11 885 (BS EN ISO 11885:2009)
		Molecular absorption spectrometry	0.04 in boron	NFT 90-041
Hydrazine (N_2H_4)		Molecular absorption spectrometry	0.005	ASTM 1385-07
Morpholine (C_4H_9ON)		Capillary electrophoresis	0.3	No existing standard
Ethanolamine (C_2H_7ON)		Capillary electrophoresis	0.3	No existing standard
Nitrogen (N)	Ammonium	Molecular absorption spectrometry	0.01	NFT 90-015-2 (ISO 7150-1:1984)
		Capillary electrophoresis	0.3	No existing standard
	Nitrites	Ionic chromatography	0.015	NF EN ISO 10304-1
		Molecular absorption spectrometry	0.01	NF EN 26 777 (BS EN 26777:1993)
	Nitrates	Ionic chromatography	0.025	NF EN ISO 10304-1
		Flow analysis and spectrometric detection	0.2	NF EN ISO 13 395 (BS EN ISO 13395:1996)
Phosphate		Molecular absorption spectrometry with bismuth phosphomolybdate	0.1	No existing standard
		Ionic chromatography	0.1	NF EN ISO 10304-1
		Molecular absorption spectrometry with ammonium molybdate	0.015	NF EN ISO 6878
Detergents		Molecular absorption spectrometry	0.1	NF EN 903 (BS EN 903:1994)
Total metals		Inductively coupled plasma	0.001 to 0.015 depending on elements	NF EN ISO 11 885 (BS EN ISO 11885:1998)
Total suspended solids (TSS)		Filtration through glass fibre filters	2	NF EN 872 (BS EN 872:2005)
Chemical oxygen demand (COD)		Molecular absorption spectrometry	15	ISO 15705:2002

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[1] When they exist

Sub-chapter 8.4 - Table 4: Reference standards of measurement methods for suspended solids, sulphate and iron concentrations

Parameter	**Requirement**	**Sampling location**	**Measurement method**	**Reference Standard**	**Quantification Limit (mg l^{-1})**
Suspended Solids	Maximum concentration at the Demineralisation Station outlet before dilution	Demineralisation Station outlet	Filtration through glass fibre filters	NF EN 872 (BS EN 872:2005)	2
Sulphates	Maximum concentration at the Demineralisation Station outlet before dilution	Demineralisation Station outlet	Molecular absorption spectrometry with barium chloride	NFT 90-040	5
Iron	Maximum concentration at the Demineralisation Station outlet before dilution	Demineralisation Station outlet	Molecular absorption spectrometry	NFT 90-017 (ISO 6332:1988)	0.01

Sub-chapter 8.4 - Table 5: Table Reference standard of measurement method for BOD_5 determination

Parameter	**Requirement**	**Sampling location**	**Measurement method**	**Reference Standard**	**Quantification Limit (mg l^{-1})**
BOD_5	Concentration increase	Downstream of the wastewater purification stations	Dissolved oxygen measurement	NF EN 1899 (BS EN 1899:1998)	0.5

Sub-chapter 8.4 - Table 6: Reference standard of hydrocarbon concentration measurement

Parameter	Requirement	Sampling location	Measurement method	Reference Standard	Quantification Limit (mg l^{-1})
Total hydrocarbons	Maximum immediate concentration	Output from all of the Plant Sewer System SEO outfalls	Gas Chromatography	NF EN ISO 9377 (BS EN 9377: PART 2:2000)	0.1

Sub-chapter 8.4 - Table 7: Reference standards of measurement methods for additional parameters

Parameter	Requirement	Sampling location	Measurement method	Reference Standard	Quantification Limit (mg l^{-1})
Residual oxidants	Concentration increase	In each discharge pond	Colorimetry	NF EN 7393 (BS EN ISO 7393: PART 2:2000)	0.03
Chlorine produced	-	Electrolyser output	Titration	NF EN ISO 7393 (BS EN ISO 7393: PART 1:2000)	0.03

Sub-chapter 8.4 - Table 8: Summary of the main outputs from the EPR discharges monitoring programme

Gaseous radioactive discharges	Liquid radioactive discharges	Chemical substances
• Flow rate emission measurement at the stack; • Continuous measure of gross beta activity with alarm threshold in Bq m^{-3} (reported at the Control room); • Specific analyses: iodine isotopes, noble gases, tritium, carbon-14 and other activation or fission products; and • Check of the absence of gross alpha activity.	• Batch discharges from tanks: analyses prior to and after discharge: tritium, gross beta and gross gamma activities, spectrometry: gross beta activity, tritium; and • Continuous measurement of radioactivity on the outfall (T (0KER [LRMDS]) and S (0TER [ExLWDS]) tanks) with alarm threshold (in Bq m^{-3}) in gross gamma activity enabling automatic stop of discharges.	• Discharges from tanks: analyses prior to and after discharges; • Outfall emissions; and • Emissions to air (if needed).

SUB-CHAPTER 8.4 – REFERENCES

External references are identified within this sub-chapter by the text [Ref-1], [Ref-2], etc at the appropriate point within the sub-chapter. These references are listed here under the heading of the section or sub-section in which they are quoted.

1. INTRODUCTION

[Ref-1] Process and Information Document for Generic Assessment of Candidate Nuclear Power Plant Designs. The Environment Agency. January 2007. (E)

[Ref-2] Monitoring of radioactive discharges to Atmosphere from Nuclear Facilities. Technical Guidance Note (Monitoring) M11. Environment Agency. 1999. (E)

[Ref-3] Monitoring of radioactive discharges to Water from Nuclear Facilities. Technical Guidance Note (Monitoring) M12. Environment Agency. 1999. (E)

[Ref-4] Monitoring of discharges to water and sewer, Technical Guidance Note (Monitoring) M18. Version 1. Environment Agency. 2004. (E)

2. MONITORING PROGRAMME OF GASEOUS RADIOACTIVE DISCHARGES

2.1. RADIOACTIVE GASEOUS DISCHARGES SPECTRA

[Ref-1] Monitoring of radioactive discharges to Atmosphere from Nuclear Facilities. Technical Guidance Note (Monitoring) M11. Environment Agency. 1999. (E)

[Ref-2] Commission Recommendation of 18 December 2003 on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation. C(2003)4832 & (2004/2/Euratom). Official Journal of the European Union. 6 January 2004. (E)

3. MONITORING PROGRAMME OF LIQUID RADIOACTIVE DISCHARGES

3.1. RADIOACTIVE LIQUID DISCHARGES SPECTRA

[Ref-1] Monitoring of radioactive discharges to Water from Nuclear Facilities. Technical Guidance Note (Monitoring) M12. Environment Agency. 1999. (E)

[Ref-2] Commission Recommendation of 18 December 2003 on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation. C(2003)4832 & (2004/2/Euratom). Official Journal of the European Union. 6 January 2004. (E)

6. COMPARISON WITH ARRANGEMENTS IN PLACE AT SIZEWELL B FOR RADIOACTIVE DISCHARGES

[Ref-1] Decision Document and Authorisations for future regulation of disposals of radioactive waste under the Radioactive Substances. Act 1993 at British Energy generation Limited’s nuclear sites. Environment Agency. 2006. (E)

7. MONITORING PROGRAMME ASSOCIATED TO CHEMICAL DISCHARGES

7.1. EMISSIONS SPECTRA

7.1.3. Emissions to air

[Ref-1] Sampling requirements for monitoring stack emissions to air from industrial installations. Technical Guidance Note (Monitoring) M1. Version 4. Environment Agency. 2006. (E)

[Ref-2] Monitoring of stack emissions to air. Technical Guidance Note (Monitoring) M2. Version 4.2. Environment Agency. 2007. (E)

7.3. COMPLIANCE WITH BAT REQUIREMENTS FOR CHEMICAL DISCHARGES MONITORING AND INTERNATIONAL STANDARDS

[Ref-1] Guidance for the Recovery and Disposal of Hazardous and Non Hazardous Waste, Sector Guidance Note IPPC S5.06. Issue 4. Environment Agency & Environment and Heritage Service. 2004. (E)

8. CONCLUSION

[Ref-1] The Radioactive Substances Act 1993. HM Stationery Office. ISBN 0-10: 0105412937. (E)

[Ref-2] Pollution Prevention and Control Regulations 2000. SI No. 1973. The Stationery Office Ltd. ISBN 978-011099621-9. (E)

[Ref-3] Commission Recommendation of 18 December 2003 on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation. C(2003)4832 (2004/2/Euratom). Official Journal of the European Union. 6 January 2004. (E)