Environment Agency

Evidence

Scoping study: discharges from boiling water reactors

Report – SC130018/R

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This report is the result of research commissioned and funded by the Environment Agency.

Published by:
Environment Agency, Horizon House, Deanery Road, Bristol, BS1 5AH

www.environment-agency.gov.uk

ISBN: 978-1-84911-349-6

Further copies of this report are available from our publications catalogue: http://publications.environment-agency.gov.uk

or our National Customer Contact Centre: T: 08708 506506

E: enquiries@environment-agency.gov.uk.

Author(s):
Nick Hughes
Anna Macdonald
Sandra Moita

Dissemination Status:
Publicly available

Keywords:
Nuclear power stations; discharges; radioactive substances

Research Contractor:
AMEC Environment and Infrastructure UK Limited, Windsor House, Gadbrook Business Centre, Gadbrook Road, Northwich, Cheshire CW9 7TN
+44 (0) 1606 354800

Environment Agency's Project Manager:
Roger Timmis, Evidence Directorate

Project Number:
SC130018

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Miranda Kavanagh

Director of Evidence

Executive summary

The reactor designs being considered for new nuclear power plants in the UK include advanced boiling water reactors (ABWRs). ABWRs are an update on previous boiling water reactors (BWRs) of which many are in operation around the world. BWRs can therefore provide useful indicative information on ABWRs – including information on potential discharges to the environment from ABWRs of radioactive and non-radioactive substances.

The Environment Agency and the Office of Nuclear Regulation are currently undertaking a generic design assessment for ABWR technology in the UK. The design that is being proposed for sites at Wylfa on Anglesey and Oldbury in Gloucestershire, is the 'UK ABWR' design of Hitachi-GE Nuclear Energy. Consequently, the current generic design assessment is focused on the Hitachi UK ABWR design.

The main objective of this study is to collate and present baseline data and relevant operational information for radiological and chemical discharges and solid waste arisings from an agreed list of candidate predecessor BWRs, to enable the Environment Agency to set discharges and limits which reflect best available technique (BAT) and global practice and performance.

Any available data regarding abnormal operations is also of interest. This study also highlights the key recommendations and next steps for future work in this area to fully achieve these objectives.

Through a structured screening process, a number of appropriate reactors which have similar technology and operational approaches to those of the UK ABWR were identified and relevant operators and regulators were identified and contacted to seek appropriate data. These comprised 23 reactors distributed between Europe, the USA, Mexico and Japan.

Key data

For the European reactors a combination of both publically and non-publically available discharge data was available for radioactive discharges and to various levels of detail. Non-radioactive chemical and waste data was also generally available, although again there were differences in the extent and level of detail between reactors. Contextual data on outage periods and fuel failures was also obtained for some reactors although in the time available to the study, it was generally not possible to undertake additional follow-up activities to access further data or to drill down to link, for example, operational conditions with discharge data.

For the Japanese reactors limited radioactive data and no non-radioactive data was obtained. The research into reactors in Japan during this pilot project was affected by the current situation in the sector, whereby operators and regulators are heavily involved in activities to secure the restart of power stations following the shutdown after the Fukushima incident.

The key data source for US candidate reactor plants was the Nuclear Regulatory Commission (NRC) effluent database which makes available to the public annual radioactive effluent release reports submitted by all nuclear plant operators. These reports provide data on the quantities of radionuclides in liquid and gaseous effluents released from each reactor plant.

A response from Exelon Generating Co., LLC provided useful information on the US regulatory regime and dose limits for nuclear plants. Exelon also provided us with directions to the relevant annual effluent reports for the candidate plants which they operate and to information on their current ABWR application on the NRC website.

Responses were also received from a number of the US Environmental Protection Agency regional departments regarding their regulation of non-radiological discharges at the relevant candidate reactor plants.

Recommendations for further work

There are a number of aspects of the work commenced during this pilot study which it has not been possible to complete but which are important to enable the Environment Agency to realise the project objectives. These should be addressed in a new study, and our recommendations for such future work are listed below under three headings.

Further work on current data and accessing further data:

- Further manipulate the discharge data and in-depth analysis using operational information.
- Conduct a gap analysis on the data already obtained and seek to address these gaps through further contact with operators. Obtain further contextual data from operators, as the metadata is an important supplement to the actual discharge data such as outages, fuel failure and normalisation information, and relate this contextual data to the discharge data obtained.
- Further investigate discharge trends (ideally over a 10-year period).
- Focus data collection on a smaller number of reactors/stations where significant reliable data has already been obtained, to build a complete picture of all relevant aspects.

Interpretation of data and development of 'ideal' metrics:

- Interpret the data for a smaller number of stations to better understand the relationship between power generation, discharges, operation etc, to enable data normalisation and key metrics to be developed.
- Use these key metrics to develop a template for future data collection and processing to enable comparisons between reactors to be made.

Further work to inform the wider context:

- Understand cultural differences between territories which may result in difference in aspects such as nomenclature, basis of limits (monitoring/measurement or calculation) and quality assurance for monitoring and dose calculations for the regulator or licensee.
- Establish whether regulators have data repositories for discharge information similar to the ELGA database where all Consejo de Seguridad Nuclear's liquid and gaseous data is stored for Spanish nuclear power plants. If so, investigate the possibility of obtaining access to this.
- Develop a better understanding of the principle of optimisation in relation to discharges to the environment in different countries and how the proposals for optimisation demonstrate BAT.
- Consider the costs relating to the abatement technologies used. This information, which is an element of demonstrating the implementation of BATs, was not available within the timeframe of the pilot study.
- Further research the regulatory function of the Nuclear Regulation Authority (NRA) in Japan, to better understand its future approach to discharge limit setting and the management of non-radiological discharges to the environment.
- Establish the chosen treatment methods and waste packages to manage radioactive solid waste from BWRs. This is important to enable waste forecasting to ensure that the UK has adequate provision of treatment plants and interim storage facilities.
- Informed by the outcome of these further investigations, formulate some conclusions on potential discharge restrictions for the proposed ABWRs.

Acknowledgements

AMEC Environment and Infrastructure UK Limited would like to acknowledge the support provided by the Environment Agency staff. We also thank the operators and regulators who provided data on discharges and operations for their work and cooperation.

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1.1 Project background

The reactor designs being considered for new nuclear power plants in the UK include advanced boiling water reactors (ABWRs). ABWRs are an update on previous boiling water reactors (BWRs), which are in operation in many countries around the world. BWRs can therefore provide useful indicative environmental information on ABWRs – including information on potential discharges to the environment from ABWRs of radioactive and non-radioactive substances.

The Environment Agency and the Office of Nuclear Regulation are currently undertaking a generic design assessment for ABWR technology in the UK. One design that is currently being proposed in the UK (at sites at Wylfa on Anglesey and Oldbury in Gloucestershire) is the 'UK ABWR' design of Hitachi-GE Nuclear Energy. Consequently, the current generic design assessment is focused on this UK ABWR design.

An important element of this assessment is to determine whether the proposals for reducing radiological and chemical discharges to the environment via air and water and reducing the generation of solid waste represent best available techniques (BAT) to enable the Environment Agency to set discharges and limits which reflect BAT and global practice and performance.

Due to the limited published radiological and chemical discharge data for ABWRs, this study focuses on the collation of discharge data, where possible, from selected existing BWRs around the world as a means to help inform the decision-making process relating to the proposed new UK ABWRs. The choice of which BWR reactors to target to obtain appropriate data was based on a variety of factors such as age/generation of the reactor, location, fuel type and similarities of operational and abatement practices with the proposed new UK ABWRs. The selection criteria are discussed in section 3 of this report.

Chemical and radiological discharge data have been analysed previously for other reactor designs (pressurised water reactors and economic simplified BWR). These reports can be found in the 'New build of nuclear reactors' section in the following link: http://intranet.ea.gov/policies/environmentalwork/compliance/60849.aspx. These reports have helped the Environment Agency to understand the level of permitting at similar reactor design sites and use this information to inform decision making on the likely environmental performance of the proposed new reactor designs.

1.2 Objectives

The main objective of this study is to collate and present baseline data and relevant operational information for radiological and chemical discharges and solid waste arisings from an agreed list of candidate predecessor BWRs. Any available data regarding abnormal operations is also of interest. This study also makes recommendations and suggests next steps for future work in this area to fully achieve these objectives.

This is an initial pilot study which will act as a platform for future more detailed investigation and analysis. The purpose of any future work would be to provide additional information to enable the Environment Agency to make more robust informed decisions on environmental discharge limits for the proposed UK ABWR designs than has been possible from this pilot study.

1.3 Scope of this report

The scope of this report is to present the findings from the completion of the following tasks:

- Identification and selection of suitable predecessor candidate BWRs, using a methodology developed by AMEC in conjunction with the Environment Agency.
- Collection and collation of relevant available information required for this study from a detailed desk-based review.
- Contact the operators and the regulatory authorities of the selected BWRs, to request relevant information, supported by a suitable introduction to the study and an agreed questionnaire developed by AMEC in conjunction with the Environment Agency.
- Presentation of collated data (normal operations only) and information relevant to each of the selected BWRs.
- Establish the process and methodology, and assess the problems with obtaining relevant and reliable data.
- Determine the key findings of the study and make recommendations for further investigation to provide additional information to enable the Environment Agency to make informed decisions on environmental discharge limits for the proposed UK ABWR designs which are more robust than has been possible from this pilot study.

Due to the limited timeframe available for this pilot study, the detailed interpretation and analysis of the data obtained was not included within the scope of this study, as agreed with the Environment Agency.

1.4 Assumptions

The key assumption of this scoping study is that discharge data and operational information would be available for the chosen predecessor reactors. Although this data might not be provided to the research team in the timescale available to undertake this work, a route and process to obtain this data would be identified and would be shared as part of this study report.

As described in section 1.5 below, this assumption was not always the case, with differences in both the amount and level of data obtained (as part of this pilot study) and the clarity of the route and process necessary to obtain this data (as part of this and any future study).

1.5 Constraints of the study

The main constraints experienced in this study relate to the following areas:

i. Limited response from candidate BWR operators and regulatory authorities within the timeframe of this project. In general, there was a limited response received from target territories. This prevented the ‘inverted pyramid’ approach to research being implemented, whereby an initial approach to obtaining data for 23 identified reactors would be followed by going forward with several reactors to obtain more detailed data and access more information. The main reason for this not being possible was the timeframe available to the project to approach the operators and regulators asked to participate in the study and to obtain relevant data where this was not publicly available.

ii. Manipulation of the discharge data. In some cases the data obtained for certain countries was not in a format that could be easily manipulated, and given the time constraints, the further processing of some data has not been possible. The time required to manipulate data has limited the ability of the research team to critically review all the data in terms of its basis (e.g. actual concentrations or limit of detection, uncertainty, sample size).

iii. Cultural differences. These include language barriers. The requirement for the translation of key reports for some candidate territories, and different reporting regimes, has limited the amount of data which it has been possible to extract.

iv. Availability of relevant data required for the study. Although liquid and gaseous discharge data is generally available for US and European plants, it has been more difficult to obtain publicly available data for the Mexican plant. While publicly available data was obtained for the Japanese plants, this related to radioactive discharges only.

v. Limited publicly available information on other focus areas of this study has prevented the following fields of research being addressed in any significant detail:

- Interpretation of BAT and approaches to optimisation in the target territories and different authorities. Nevertheless, some overall differences in approach have been identified (see section 4).
- The approaches can broadly be described as either being based on a reference group target or process/operational, linked to technology and operation. Some broad comments are summarised as:
    - Japan – the approach does not relate specifically to the use of BAT, although it is noted that the concept of optimisation is inherent in the principle of ‘as low as reasonably practicable’ (ALARP), a common approach to radiation protection;
    - USA – the approach relates to the use of ‘as low as reasonably achievable (ALARA) and a prescribed limit based approach. BAT is the approach used for non-radioactive discharges;
    - Europe – the demonstration of optimisation uses BAT, with safety standards also a key driver of performance.
- Liquid and gaseous waste abatement techniques for certain candidate reactors.
- Details of operators’ proposed response to specific abnormal events such as fuel (pin) failures.

2 ABWR technology

The ABWR was developed in the 1980s by three organisations (General Electric (GE), Hitachi and Toshiba) and is a Generation III+ nuclear reactor design. The main objective behind the ABWR was to develop a reactor that harnessed the best features of existing BWR designs with new technologies and modular construction methods. Safety improvements are afforded the highest priority through enhancing both the safety and reliability of structures, systems and components (Hitachi 2014).

For the purposes of this pilot study it is appropriate to describe the sources of discharges and the ABWR systems which relate to the management of gaseous, liquid and solid wastes. While a general process description of the ABWR is not included in this report, a basic understanding of the ABWR (as relates to both UK and global operation) can be obtained through consulting the website of the reactor vendor: http://www.hitachi-hgne-uk-abwr.co.uk/.

The ABWR employs three systems for the management of radioactive wastes:

- off-gas system
- liquid waste treatment system (LWTS)
- solid waste treatment system (SWTS)

Compared with information currently available relating to radioactive wastes, information relating to the management of non-radioactive waste from ABWRs is limited. Waste management of non-radioactive waste streams is site specific, in that different sites have different practical arrangements, in compliance with the appropriate territory environmental regulations. General commentary on the management of non-radioactive waste can be found below from a review of available literature. It should be noted that information in this section is not specific to the UK and reflects approaches elsewhere in the world.

2.1 Gaseous discharges

2.1.1 Radioactive gaseous waste – ABWR off-gas system

The ABWR off-gas system has two main functions:

- to recombine the flammable gases of hydrogen (H_2) and oxygen (O_2) into steam (these gases are generated from the radiolysis of reactor cooling water);
- to reduce the rate of emissions of radioactive gaseous waste discharged to the environment (Hitachi 2014).

Prior to discharge to the environment, the off-gas is subjected to a series of abatement phases. Firstly, the off-gas is cooled and dried before passing through charcoal adsorber units which reduce the radioactivity of the gaseous waste and allow xenon (Xe) and krypton (Kr) to decay (Hitachi 2014). The second abatement phase is filtration, which removes radioactive particles from the off-gas stream before discharge to the environment via a stack (Hitachi 2014). The off-gas system contains monitors to provide real-time monitoring of radioactivity levels in the gaseous discharge.

2.1.2 Non-radioactive gaseous waste

Non-radioactive gaseous discharges are limited and relate to those associated with backup power supplies in the form of diesel and combustion turbine generators (US NRC 2011). It is not uncommon for ABWR sites to use incineration as a treatment method for combustible wastes. In the context of the UK, any requirement for incineration will be subject to a BAT assessment and separate environmental permit (NIA 2014).

2.2 Liquid discharges

2.2.1 Radioactive liquid waste – ABWR LWTS

The function of the LWTS is to control, collect, process and store liquid radioactive waste generated from normal operations (Hitachi 2014). Operating on a batch basis, the LWTS makes provisions for sampling at set process points. Protection against accidental discharge is provided by the detection and alarm of abnormal conditions and management controls (Hitachi 2014).

Within the LWTS, liquid waste streams are segregated at source and diverted to one of three subsystems:

- low conductivity LWTS;
- high conductivity LWTS;
- laundry drain system.

Source segregation of the different radioactive liquid wastes enables each stream to be processed separately according to its chemical properties (Hitachi 2014).

2.2.2 Non-radioactive liquid waste

Non-radioactive liquid waste streams include domestic water/wastewater, water from non-radioactive floor drains and plant blowdown systems. Abatement of non-radioactive liquid waste streams is limited to treatment systems for surface water and groundwater (US NRC 2011). Water treatment chemicals consist of biocides, corrosion and scale inhibitors, and silt dispersant. The ABWR contains no other non-radioactive liquid wastes containing chemicals or biocides (US NRC 2011).

Note: Cooling water is not included in this section and would be addressed under a separate permit.

2.3 Solid waste

2.3.1 Radioactive solid waste – ABWR SWTS

The function of the SWTS is to control, collect, process and package solid radioactive waste generated from normal operations. Following generation, the wastes are transferred offsite or kept onsite for interim storage (Hitachi 2014).

Solid radioactive waste from ABWRs is split into two categories: wet solid wastes and dry solid wastes. Wet solid wastes typically include secondary wastes from onsite processes such as spent ion exchange bed resin and filter backwash arisings from the operation of the LWTS.

Dry solid wastes comprise secondary wastes such as HEPA filters, protective clothing, contaminated tools and general radioactive waste arisings from day-to-day operations. The SWTS processes both low level waste and intermediate level waste.

2.3.2 Non-radioactive solid waste

Non-radioactive solid waste comprises hazardous and municipal waste. The waste streams will be generated from routine plant operations and will consist of waste oil, wood, metal, resins and sludges (US NRC 2011). These waste streams would be segregated at source and transferred offsite for processing.

3 Methodology

3.1 Identifying suitable candidate reactors

Initially 77 operational BWRs and ABWRs were identified as potential candidate predecessor reactors within the following territories: Japan, USA, Sweden, Switzerland, Spain, Finland, Germany, India and Mexico. This initial list of reactors includes all the BWRs and ABWRs which are in operation globally.

From this initial list, the focus was placed on selecting candidate reactors from territories which have operational experience of BWRs and to some extent those that are forerunners in BWR/ABWR technologies.

Based on an approach agreed with the Environment Agency, 38 BWRs were selected from the initial list, taking into account the following selection criteria:

i. The design of the reactor(s) at each candidate nuclear power plant. Where possible, reactors chosen were of the most recent design and would be most similar to the new ABWR design. For the purpose of this study, BWR designs of Generation 4 type onwards (BWR 4 to BWR 6) were selected.

ii. The operational period of the reactor. Reactors that were in commercial operation from 1980 onwards were selected. This operational period allowed the inclusion of older reactors which had designs relevant to the first criteria above. In the USA the majority of the BWRs are pre-1990 and therefore an earlier operational start date than the 1980 noted above was applied.

It was not possible in all cases to identify reactors that met the above main criteria. Therefore, additional factors considered in the selection process included:

iii. A type of effluent treatment technology (where information was available) similar to the proposed ABWR. This criterion was applied in particular to the selection of the European reactors where they did not necessarily meet the first criterion (above).

iv. The type of fuel used. Only reactors that used enriched uranium fuel type were selected.

A further screening exercise was undertaken to reduce the list of 38 BWRs to a more manageable number within the timeframe of the project. Along with the screening criteria above, the following additional criteria were applied:

- Where multiple units exist at the same site, the most recent iteration was chosen.
- Priority was given to larger reactors (or companies) in terms of size (capacity) within each territory.
- The availability of relevant data. Preference was given to those reactors where relevant data was publicly available or where data was considered to be more accessible based on an initial desk/web-based review.
- Existing relationships to support the collection of data, for example AMEC's relationship with the US operator Excelon.

- Other factors including the ease of navigating company websites and company culture were also considered.

Following this second round of screening, a final list of 23 candidate BWRs and ABWRs were selected for inclusion in the study. The final list of candidate reactors and territories is presented in Table 3.1.

Table 3.1 List of candidate reactors

Reactor name	Country	Start of commercial operation
Clinton-1	USA	1987
Grand Gulf-1	USA	1985
LaSalle-1	USA	1984
LaSalle-2	USA	1984
Limerick-1	USA	1986
Limerick-2	USA	1990
Nine Mile Point-2	USA	1988
Perry-1	USA	1987
Susquehanna-1	USA	1983
Susquehanna-2	USA	1985
Fukushima II (Daiichi) Nuclear Power Plant Units 2 and 4	Japan	1984 and 1987
Hamaoka Nuclear Power Plant Unit 5	Japan	2005
Kashiwazaki-Kariwa Nuclear Power Plant Units 4 and 5	Japan	1994 and 1990
Kashiwazaki-Kariwa Nuclear Power Plant 6 (ABWR)	Japan	1996
Kashiwazaki-Kariwa Nuclear Power Plant 7 (ABWR)	Japan	1997
Shika Nuclear Power Plant Unit 1	Japan	1993
Shika Nuclear Power Plant Unit 2 (ABWR)	Japan	2006
Cofrentes Nuclear Power Plant	Spain	1985
Forsmark Nuclear Power Plant Unit 3	Sweden	1985
Leibstadt Nuclear Power Plant	Switzerland	1984
Laguna Verde Nuclear Power Plant Unit 2	Mexico	1995

Of the BWRs selected, 10 BWRs were located in the USA, 9 in Japan and 1 each in Spain, Sweden, Switzerland and Mexico.

The full initial list of 77 reactors along with their associated operational details is provided in Appendix A, Table A1. The final 23 candidate reactors selected (which are highlighted in green in Table A1) comprised 20 BWRs and 3 ABWRs.

3.2 Establishing operator and regulator contacts

As part of the selection process, the corresponding operators and regulators for the candidate reactors had been identified and any established lines of communication (email addresses or telephone numbers) had been considered. If no previous contact information existed, operating companies’ and regulatory bodies’ websites were accessed for email addresses and telephone numbers of personnel with which the initial contact could be made. In some cases, a generic ‘Contact Us’ email address was all that could be found. The International Atomic Energy Agency (IAEA) was contacted to see if they had contact information it could share. The response stated that the only information IAEA possesses is the contact information found at the end of the individual

Country Nuclear Power Profiles (http://www-pub.iaea.org/MTCD/publications/PDF/CNPP2013_CD/pages/index.htm).

A detailed log was kept of all contacts made with both operators and regulators to keep track of progress. This can be found in Appendix A, Table A2.

3.3 Information requests

The next step was to develop the 'request for information' and it was decided that this should take a similar approach to that used successfully for previous work undertaken for the Environment Agency on chemical discharges from pressurised water reactors. The 'request for information' comprised a letter from the Environment Agency explaining the context of the request and how the information was going to be used and a list of the type of information required. Two different 'requests' were developed, one for the regulators and one for the operators.

For the operators, along with the request for actual discharge data for aerial and liquid radioactive and non-radioactive discharges (from 2003 to 2013 if available), operational contextual information was sought. It was deemed important to understand the operational context of each reactor within the timeframe of any discharge data provided, for example utilisation of the plant each year and the frequency of maintenance outages. This contextual data would help to account for any peaks or troughs in the discharge data. Other data requested related to the gaseous and liquid abatement technologies used and how the plant manages fuel failures to gain an understanding of how these related to the new ABWR design proposed.

The request letter to the regulators was for information relating to gaseous and liquid radioactive and non-radioactive discharge data (from 2003 to 2013 if available) and a description of the regulatory regime within the territories, including a request for the environmental permit/licence for the particular reactor.

The first point of contact to operators and regulators was made via email, in their respective languages, with the 'request for information' attached to the email, again translated into the appropriate language where required. Where possible, the information request was addressed to an environmental or radiation protection specialist, therefore giving the best possible opportunity to receive the sort of information required. However, where there was no other option, generic 'Contact us' email addresses were used, to varying degrees of success. After making the initial contact via email and a subsequent short waiting period for response (typically no more than 5 days), follow-up telephone calls or emails were made, where appropriate, to operators and regulators who had not responded.

There were several challenges encountered when trying to obtain discharge data from operators and regulators. The three main challenges are discussed below:

- One obvious challenge was the language barrier for countries such as Japan, Switzerland, Spain and Mexico. The initial requests had been translated into German and Spanish for the Swiss, and Spanish and Mexican contacts, respectively. During the follow-up period where ideally a telephone conversation was needed, German and Spanish speaking AMEC staff were used to develop a line of spoken communication which proved helpful in directing requests towards a specific individual.

- Another significant challenge was the lack of responses from both operators and regulators. In Japan, it became clear that all nuclear power generation had been suspended as a result of the Fukushima incident and therefore it was highlighted that responses from the Japanese operators and regulators were likely to be very limited as they were engaged with preparing the required regulatory submissions and assessments to restart generation.

- Thirdly, the response time available to the project from the operators and regulators was in the order of 10–14 days, following the despatch of the requests for information and translating these documents where required. This was insufficient to receive any data additional to that which was readily and publically available and did not enable further 'drilling down' to obtain reactor-specific data.

4 Regulatory regimes in chosen territories

This section describes the various regulatory settings for the territories in which the final 23 candidate reactors are located.

These are described under each country as follows:

- Sections 4.1 to 4.3 European countries
- Section 4.4 Japan
- Section 4.5 USA
- Section 4.6 Mexico

The research has identified a number of areas where there is the potential for differences in approach between the UK and the territories included in this research. These include terminology, the interplay between technologies and monitoring, quality assurance and reporting. In the context of collecting data within the scope of this research project, this can lead to uncertainty regarding the meaning and applicability of the data.

Possible differences between the UK approach and the territories researched which would benefit from further assessment include:

- terminology differences (e.g. waste radioactivity descriptions in Japan);
- relationship between the use of technology and monitoring in regulation;
- quality assurance process for monitoring, especially when provided by licensee;
- basis of reported emission data, by calculation or monitoring;
- accessibility of data and the ability to interpret the data.

4.1 Sweden

4.1.1 Regulatory regime

Sweden has an integrated regulatory authority for nuclear safety and radiation protection, the Swedish Radiation Safety Authority (SSM) (IAEA 2013b). SSM is an administrative authority reporting to the Ministry of Environment with the responsibility of ensuring key legislation on nuclear activities and radiation protection is followed.

While SSM is an independent regulator, it does not have the final decision-making authority for issuing a licence for a nuclear facility. This authority rests with the Ministry of the Environment, and the Ministry uses SSM as a ‘competent authority’ due to its technical expertise and governmental status to advise on licensing matters. Nuclear power plants in Sweden have both government permits and permits under the Environmental Code.

The licensee/operator of the nuclear reactor must report the following discharge measurements for:

- air: inert gases, iodine, carbon-14, tritium and particle-bound radioactive substances;
- water: tritium and gamma-emitting radioactive substances;
- air and water: strontium-90 and alpha-emitting radioactive substances.

These discharges are reported every half year. Monitoring and measurements for discharges of radioactive substances from nuclear facilities are performed by the licensee. The results of the measurements are submitted to SSM for review and reported to the European Union. SSM regularly carries out control measurements of the radioactive discharges and inspects the nuclear facilities. In addition, the licensees of the nuclear facilities and SSM meet twice a year to discuss issues of interest (IAEA 2012).

4.1.2 Demonstration of optimisation

SSM has implemented a low dose constraint relating to the discharge of radioactive substances from nuclear facilities into the environment, according to the requirements of the IAEA Basic Safety Standards (IAEA 2012). For nuclear facilities, the limitation of the discharges is based on the optimisation of radiation protection using the best available techniques. Dose calculations are carried out only by the licensee and, if a calculated effective dose is higher than a tenth of the stipulated dose constraint, more specific calculations have to be performed.

One effective strategy to reduce releases of radioactivity is to reduce the source term. Aside from activation products, the source term consists of fission products and trans-uranium elements. These are only available for release if they have escaped from the fuel. It is therefore considered prudent to keep the amount of fuel failures to a minimum, and when they do occur the failed fuel should be carefully observed and removed from the core before contributing to unacceptable core contamination.

Various abatement technologies are used in Swedish BWRs to reduce the radioactivity levels of the resultant emissions, both gaseous and liquid. Table 4.1 highlights the specific measures used in Sweden.

Table 4.1 Abatement technologies used in Sweden

Type of discharge	Abatement used
Gaseous	HEPA filters + carbon filters
	Recombiners
	Delay tanks (sand)
	Charcoal columns
Liquid	Centrifugation
	Evaporation
	Storage tanks

4.1.3 Monitoring and management of discharges to the environment

Radioactive discharges

SSM has not defined any radionuclide-specific discharge limits for Swedish nuclear power stations (EU 2009). Limitation of releases is being implemented through the restriction of dose to the reference group members. For each nuclear facility (e.g. each reactor at Forsmark), and for each radionuclide that may be released, specific release-to-dose factors have been calculated (97 radionuclides that may be discharged to the marine environment and 159 radionuclides that may be emitted to air). The dose contributions from all monitored radionuclides are summed, and this sum shall not exceed 0.1 mSv for a calendar year. Facilities are required to notify SSM of any abnormal releases or if the dose limit of 0.01 mSv/month to any individual is exceeded.

Discharges to the air via the main stacks of nuclear power reactors are controlled through continuous nuclide-specific measurements of volatile radioactive substances such as noble gases, through nuclide-specific measurements of continuously collected samples of iodine and particle-bound radioactive substances, and through the measurement of carbon-14 and tritium (EU 2009).

Discharges to water are controlled through the measurement of representative samples for each release pathway. The analyses include nuclide-specific measurements of gamma and alpha-emitting radioactive substances as well as, where relevant, strontium-90 and tritium. The SSM conducts control measurements on representative water samples from each pathway from the month before and after an outage period. The samples are analysed for gamma radiation.

Solid waste generation

All types of wastes must be approved by SSM before disposal. This involves inspections to check for compliance with regulations and with the approved waste type description of the waste generated at both the waste producer and the waste disposal sites (IAEA 2012).

Non-radioactive discharges

Non-radioactive discharges or chemical discharges are mainly controlled by the Dangerous Substances Directive (76/464/EEC), which established two lists of compounds of concern relating to the pollution of inland, coastal and territorial surface waters. List I deals with substances regarded as being particularly dangerous because of their toxicity, persistence and bioaccumulation; therefore pollution by List I substances must be eliminated. List II substances are less dangerous but nevertheless have a deleterious effect on the aquatic environment; therefore pollution by List II substances must be reduced.

The Dangerous Substances and related directives provide a basis for a holistic approach to the management of water resources across Europe and contained within the Water Framework Directive (2000/60/EC). This single framework legislation expands the scope of water protection to all bodies of water, surface water and groundwater, with the aim of achieving ‘good status’ by 2015. It will include the classification of all water bodies in terms of their chemical and biological quality.

4.2 Spain

4.2.1 Regulatory regime

The Energy Department within the Ministry of Industry grants the authorised discharge limits for the nuclear power plants in Spain. The Consejo de Seguridad Nuclear (CSN) or Nuclear Safety Council establishes the system of limitation, surveillance and control of radioactive effluents. It also evaluates the reported data and inspects the facilities (EU 2007).

The operators provide CSN with data on liquid and gaseous discharges and the estimated doses resulting from these releases. These data are included in the monthly operating reports and loaded into CSN's liquid and gaseous effluent database (ELGA). CSN evaluates this data, verifies compliance with established limits and conditions, and tracks discharge trends in order to detect operational occurrences and to verify that treatment systems are operative (EU 2007).

4.2.2 Demonstration of optimisation

The application of best available techniques (BAT) to demonstrate the optimisation of performance is introduced at different levels of Spanish legislation and regulation. The Regulation on Nuclear and Radioactive Facilities establishes that the licensee must continuously ensure the improvement of the nuclear safety and radiation protection conditions of its nuclear facility. The current best techniques and practices must be reviewed and improvements to nuclear safety and radiation protection implemented in accordance with CSN requirements. The licensee is also required to develop a continuous safety assessment programme taking into account the evolution of standards, technology progression (BAT), and operational experience (OSPAR 2011).

Reference levels of radioactivity for groups of nuclides have been established by the CSN for liquid and gaseous discharges. These reference levels, which indicate optimal operation of the reactor in terms of radioactive waste generation and discharges into the environment, are reviewed regularly after examining the history of discharges and emissions and their relationship to the authorised limits as well as the status of the current techniques and operating procedures adopted by the facility in radioactive waste management (OSPAR 2011).

Table 4.2 details the specific abatement technologies used in Spain to minimise both gaseous and liquid discharges.

Table 4.2 Abatement technologies used in Spain

Type of discharge	Abatement used
Gaseous	HEPA filtration Activated carbon beds for the absorption of iodine Delay tanks
Liquid	Ion exchange Evaporation Storage tanks

4.2.3 Monitoring and management of discharges to the environment

Radioactive discharges

Discharge limits are directly linked to the dose limits, and therefore no nuclide-specific discharge limits are given by the regulatory body CSN (OSPAR 2012). An effective dose value of 0.1 mSv/year applies to nuclear facilities during operation. This value, applicable to liquid and gaseous discharges considered as a whole, was established as a percentage of the dose constraint, defined by the CSN, for the nuclear power plants (0.3 mSv/year), and the dose limit for members of the public (1 mSv/year) (OSPAR 2011).

Since discharge limits in the Spanish nuclear facilities are formulated in terms of dose, operators demonstrate compliance by estimating monthly the cumulative doses in the last 12 consecutive months, considering as source terms all the radionuclides detected by effluent sampling and analysis programmes (OSPAR 2011).

Cofrentes nuclear power plant's operating licence contains all conditions relating to programmes for the continuous improvement of safety, set by the CSN, including the requirement for revising the operational dose reduction plan so that it includes quantifiable goals and precise milestones.

Solid waste generation

In Spain, the National Radioactive Waste Company (ENRESA) has ultimate responsibility for the management of all radioactive solid wastes produced at the nuclear facilities. Typical low level waste produced would be tools, plastics, clothing and gloves, whereas items such as filters and resins would be classed as intermediate level waste. Plant-specific targets aimed at minimising the volume of low and intermediate level waste produced are often implemented.

Non-radioactive discharges

See section 4.1.3, regarding non-radioactive discharges, which gives an overview for Europe.

4.3 Switzerland

4.3.1 Regulatory regime

The Federal Office of Public Health is responsible for environmental radiation supervision in Switzerland. The licensing authority for operational licences for nuclear facilities is the Federal Department of the Environment, Transport, Energy and Communications (DETEC).The Swiss Federal Nuclear Safety Inspectorate (ENSI) is the government's supervisory authority responsible for the supervision of emissions and discharges of radioactivity from nuclear facilities into air and water.

For each Swiss nuclear facility, the ENSI has issued discharge and environment monitoring regulations. These regulations contain requirements on the control of discharges and a complete programme on environmental monitoring of radioactivity and direct radiation in the vicinity of the facility. The programme is reviewed annually and modified as necessary.

4.3.2 Demonstration of optimisation

BAT/best environmental practice is implemented through Swiss national legislation, according to the terms of the OSPAR Convention, by the performance of periodic safety reviews every 10 years. The periodic safety reviews are conducted by the licensee of nuclear power plants and are evaluated by the ENSI. As part of the review, the licensee has to assess the liquid and gaseous discharges of the plant and (at the request of the inspectorate) benchmark against the corresponding discharges of similar European reactors.

If the discharges of a nuclear power plant are higher than the benchmark, the licensee has to analyse the reasons and to make suggestions to reduce the discharges in the view of the appropriateness of the means (OSPAR 2014).

Table 4.3 details the specific abatement technologies used in Switzerland to facilitate the minimisation of both gaseous and liquid radioactive discharges.

Table 4.3 Abatement technologies used in Switzerland

Type of discharge	Abatement used
Gaseous	Unclear from literature
Liquid	Centrifugation Evaporation

4.3.3 Monitoring and management of discharges to the environment

Radioactive discharges

The discharge limits are based on the source-related dose guide value of 0.3 mSv per year and per person, as the sum of doses from gaseous and liquid radioactive discharges. In the case of discharges into water, annual discharge limits are given for the releases of tritium and other nuclides. The radioactivity of nuclides excluding tritium is normalised with a reference exemption limit of 200 Bq/kg. There is also a limit set for the concentration of radioactivity in the discharged water: the concentration has to be lower than 100 Bq/kg (OSPAR 2014). No specific discharge limits have been identified for radionuclides discharged to air.

Solid waste generation

All Swiss nuclear power plants have onsite installations for the conditioning and storage of their own operational waste. The operators of nuclear power plants and the federal government established the National Co-operative for the Disposal of Radioactive Waste (Nagra), which is responsible for the implementation of permanent and safe disposal of all types of radioactive waste. Due to the constraints on future storage of radioactive waste, it is important to provide incentives for waste minimisation programmes at nuclear plants in a bid to reduce waste volumes.

Non-radioactive discharges

See section 4.1.3, regarding non-radioactive discharges, which gives an overview for Europe.

4.4 Japan

4.4.1 Regulatory regime

The regulatory regime in Japan has evolved in recent years following the accident at the Fukushima Daiichi nuclear power plant in March 2011. One of the central lessons of the accident was an improvement to the management of nuclear safety and the accompanying regulations. Prior to the accident, the Ministry of Economics, Trade and Industry (METI) had dual powers of nuclear safety and regulation and nuclear power promotion (MoE 2012).

The improvements sought to decouple the dual powers of nuclear regulation and promotion held by METI (JNES 2013). The separation of these powers led to the creation of a separate nuclear regulation body, the Nuclear Regulation Authority (NRA), an independent body affiliated to the Ministry of the Environment (MoE). As well as a separation of powers, the creation of the NRA is designed to integrate nuclear regulation functions, strengthen crisis management and reform the system of nuclear regulation (MoE 2012).

Following its creation in September 2012, the NRA initiated reform with a complete review of nuclear safety guidelines and regulatory requirements (JNES 2013). The new regulatory requirements for commercial nuclear power plants (NPPs) came into force in July 2013 and were developed to incorporate the lessons from the accident at Fukushima Daiichi nuclear power station. An outline of the new regulatory requirements has been produced by the NRA (NRA 2013).

The NRA has responsibility for nuclear power regulation, licensing and safety and is based on the United States Nuclear Regulatory Commission (US NRC). The NRA combines the roles of the Nuclear and Industrial Safety Agency (NISA) and the Nuclear Safety Commission (NSC) and will shortly subsume the Japan Nuclear Energy Safety Organisation (JNES).

4.4.2 Demonstration of optimisation

The Japanese demonstration of the optimisation concept is exhibited through their commitment to the principle of ALARP (as low as reasonably practicable) in seeking to minimise the risk to the public of exposure to radiation. The approach is that by minimising the exposure of radiation to the public, the risk to the environment is also minimised. Similarly, reducing the risk to the environment involves adherence to the principle of optimisation and, in the context of European Union, takes the form of BAT. It follows that ALARP and BAT can be said to have similar definitions in that both concepts seek to reduce risk to the public (and therefore the environment) to the lowest practicable level.

Therefore, as Japanese nuclear power plants employ the concept of ALARP in reducing the risk of exposure to radiation, it can be concluded that they demonstrate the theme of optimisation in response to exposure of both the public and the environment to radiation.

4.4.3 Monitoring and management of discharges to the environment

Radioactive discharges

The research phase of the pilot study yielded accessible information from the predecessor of the NRA, the NSC, which implies that Japan manages radiological discharges to the environment via prescribed dose limits instead of legal discharge limits of specific radionuclides as in the UK regulatory regime. The NSC has produced a series of regulatory guides (NSC 2001a, 2001b) which describe the setting of public dose limits (1 mSv effective dose) and dose targets in relation to the release of radioactive substances to the environment and keeping exposures as low as reasonably practicable. Despite their perceived focus on radiological safety, these guides do offer an insight into the management of discharges to the environment.

The discharge of gaseous and liquid radioactive waste is controlled via a prescribed dose target for the local population of 50 µSv/year in accordance with regulatory guidance (NSC 2001a, 2001b, JNES 2013). Where the release of radioactive discharges exceeds this recommended control value, further assessment to determine the radiation exposure to the local population is required taking into consideration such parameters as weather conditions and environmental monitoring (NSC 2001a). It follows that where the dose target is exceeded repeatedly 'efforts should be made to improve the radioactive release method and the facility so that dose target can be achieved' (NSC 2001a, p. 2). In effect, this means that if the 50 µSv guidance limit is exceeded, there is a requirement for the operator to explain what will be done to rectify this and prevent reoccurrence.

Within the time available for the pilot study it has not been possible to identify an NRA contact to investigate further the understanding and definition of 'efforts' and 'radioactive release method'. It is possible that these terms may refer to techniques and could be understood to represent a quasi-BAT principle and/or the abatement technology required to ensure the dose target is not exceeded.

The release of gaseous and liquid radioactive waste is controlled to ensure the dose target is not exceeded. NSC guidance (NSC 2001a) provides further commentary relating to dose targets. The annual release control target value is stipulated in the operational safety programme of the nuclear power plant based on the dose levels estimated during safety reviews and accompanying assessments (JNES 2013). It was not possible to establish whether the annual release control target value is a legal limit. During the course of the pilot study no specific information was received as to the treatment methods employed for the management of gaseous and liquid wastes at the respective BWR sites. However, given attempts to standardise the design of different generations of BWRs, abatement technologies are assumed to be broadly consistent for reactors of the same generation.

Solid waste generation

The operation of Japan's BWR reactors does not generate high level waste. Radioactive waste from the BWRs is classified as low level waste, as described in Table 4.4 (JAEA 2014a, b and c).

Table 4.4 Classification of radioactive waste from Japanese nuclear power plants

Waste classification			Example	Disposal method and depth of disposal (m)
Low level waste	Low	Very low level radioactive waste	Concrete Metals	Near-surface trench type disposal (0 m) (at point of generation)
	Level of radioactivity	Relatively lower [level] radioactive waste	Filters Used equipment Expendables	Near-surface concrete pit type disposal (0–25 m)
	High	Relatively higher [level] radioactive waste	Control rods Core internals	Sub-surface disposal (50–100 m)

Note: It is not clear from this research how the description of waste classifications in the above table align with those used in the UK.

Within the time available for the pilot study and in the absence of meaningful engagement from both the regulator and operator, it was not possible to determine the chosen treatment method or waste package for the various forms of low level waste identified in Table 4.4. With the nuclear industry having adopted a standardised approach for the management of radioactive waste, the chosen treatment methods for low level waste are not anticipated to vary greatly from those employed elsewhere in the world.

On this basis, it is assumed that the treatment of low level waste will consist of a combination of:

- direct disposal for non-combustible wastes;
- metal recycling;
- incineration of combustible wastes;
- waste compaction;
- waste immobilisation in the form of cementation or encapsulation;
- decontamination and size reduction;
- specialised treatment of redundant oversized equipment.

Similarly, the various waste packages are not anticipated to vary greatly and will most likely comprise differently sized steel boxes and steel drums designed to stringent specifications to contain the waste and the resulting secondary waste arising from the various treatment technologies.

Non-radioactive discharges

Within the time available for the pilot study, it has not been possible to gather information on the management of non-radiological gaseous, liquid and solid waste discharges to the environment from normal operations of Japan’s BWR nuclear power plants.

4.5 USA

4.5.1 Regulatory regime

Radioactive discharges

The United States Nuclear Regulatory Commission (NRC) regulates commercial nuclear power plants under the authority of the Atomic Energy Act of 1954, as Amended. In general, states do not have the authority to regulate commercial nuclear power plants, with the exception of certain economic decisions.

The principal regulatory basis for requiring effluent and environmental monitoring at nuclear power plants is the Code of Federal Regulations (CFR) Appendix A of Title 10, Part 50. The criteria require that a licensee/operator control, monitor and perform radiological evaluations of all releases, and document and report all radiological effluents discharged into the environment.

Clear reporting criteria are set out in 10 CFR Part 50 on what the NRC expects from power plant operators concerning their effluent discharges:

> *The licensee shall establish an appropriate surveillance and monitoring program to:*
>
> i. *Provide data on quantities of radioactive material released in liquid and gaseous effluents;*
>
> ii. *Provide data on measurable levels of radiation and radioactive materials in the environment to evaluate the relationship between quantities of radioactive material released in effluents and resultant radiation doses to individuals from principal pathways of exposure; and*
>
> iii. *Identify changes in the use of unrestricted areas (e.g., for agricultural purposes) to permit modifications in monitoring programs for evaluating doses to individuals from principal pathways of exposure.*

Each nuclear power plant is required to submit two annual reports to the NRC:

i. Annual Radioactive Effluent Release Report: this report lists the quantities of radionuclides released from the site in liquid and gaseous effluents and solid waste for the calendar year by monitoring (10 CFR Part 50.36a).

ii. Annual Radiological Environmental Operating Report: this report lists the measurements of radioactive materials found in the environment surrounding the power plant, and the effects (if any) on the environment.

These reports are publicly available on the NRC’s website.

Specific radionuclides are monitored for, including tritium, carbon-14, iodines, caesium, noble gases and all radionuclides in particulate form with radioactive half-lives greater than 8 days. Lower limits of detection are required, which differ depending on the type of sampling, environmental media and radionuclide or group of radionuclides being monitored. Reporting is required on a twice annual basis. Federal and state regulations also specify reporting requirements following accidental releases of radioactivity.

Non-radioactive discharges

Non-radioactive discharges from nuclear power plants are regulated at the federal and state level. Additionally, they may be regulated by local agencies or specially formed commissions. The Federal Water Pollution Control Act of 1972, also referred to as the Clean Water Act (CWA), as Amended, grants the federal government authority to control point source discharges. The regulatory framework is provided in the CFR, (mainly at 40 CFR Part 122), which implements the National Pollutant Discharge Elimination System (NPDES). NPDES discharge criteria set the minimum national standards for applicable effluents.

The US Environmental Protection Agency (EPA) administers the NPDES programme. However, in most cases, programme administration is delegated to authorised states. States and local agencies/commissions may impose stricter standards than the minimum federal criteria for non-radioactive pollutants. In addition to the NPDES programme, it should be noted that US nuclear power plants are generally subject to the same environmental regulations as most industries in the USA.

Facilities with active NPDES permits for non-radioactive liquid effluents typically submit monthly discharge monitoring reports (DMRs). DMR data is publically available with some states maintaining electronic DMR databases, while others require that the information be reviewed in person at a state facility.

4.5.2 Demonstration of optimisation

The NRC requires that nuclear power plants be designed, constructed and operated in such a manner as to maintain radioactive effluent releases to unrestricted areas ‘as low as reasonably achievable’ (ALARA) as defined in 10 CFR Part 50, Appendix I. All discharges must be optimised under the ALARA principle. Every reasonable effort must be made to maintain exposure to ionising radiation as far below the dose limits as practical, taking into account the state of technology, the economic improvements in relation to the state of technology, the economics of improvements in relation to benefits to public health and safety, and other social and socioeconomic considerations.

The risk to health is the primary criterion when determining optimisation; however, acceptability can also be taken into account. Best Available Technique (BAT) is not applied by the NRC but the EPA does consider BAT when setting non-radioactive discharge limits. The NRC does require that each reactor licence applicant include in the design of liquid and gaseous effluent treatment systems items of reasonable demonstrated technology. This means that when the technology is added sequentially to a treatment system in order of diminishing benefit return, it can (for a favourable cost-benefit ratio) effect a reduction in doses to populations within an 80 km radius of the proposed reactor.

The NRC uses collective doses for optimisation and applies a cost-benefit ratio of US$ 200,000 per man Sv. These factors among others are considered in the cost-benefit analyses.

The EPA does not however consider collective dose or occupational exposure and does not use any formal decision-aiding techniques. The EPA and the NRC consider protection to the environment, in addition to protection of human health, but apply different approaches in regulatory implementation.

Discharge limits are currently set by the NRC in terms of radioactivity levels or discharge rates and doses. For radioactivity, the resulting concentrations are measured at the boundary of the unrestricted area to determine total discharges; for dose, the limit can be specified in terms of reference group doses, highest exposed individual, or at the site boundary.

The EPA considers risks within a set probability range (1×10^{-4} to 1×10^{-6}). Usually the EPA limits apply to individually permitted or licensed facilities on a site, while in other instances the limits may be applied to the site as a whole. The EPA also uses annual dose limits, but can issue lifetime limits. The EPA's environmental radiation standards are contained in 40 CFR Part 190.

4.5.3 Monitoring and management of discharges to the environment

Radioactive discharges

To ensure the ALARA principles are met, each licence authorising nuclear reactor operation uses the offsite dose calculation manual (ODCM) to govern the release of radioactive effluents. The ODCM designates the limits for release of effluents, as well as the limits for doses to the general public. These limits are taken from 10 CFR Part 50, Appendix I and 10 CFR Part 20.1301 and from nuclear power plant specific technical specifications. The design objectives for liquid effluent releases are to maintain offsite annual doses below 3 millirem (0.00003 Sv) to the whole body and 10 millirem (0.0001 Sv) to any organ. Maintaining effluent releases within these operating limitations is generally considered to demonstrate compliance with ALARA principles.

10 CFR Part 20 requires that each plant operator conduct operations so that the total effective dose equivalent to individual members of the public from the licensed operations does not exceed 0.1 rem (0.001 Sv) in a year, which the operator can demonstrate by not exceeding the concentration values specified in the regulations when averaged over the course of a year. For tritium, this concentration value is 1×10^{-3} μCi per ml.

Furthermore, operators are required to comply with the EPA's environmental radiation standards contained in 40 CFR Part 190; that is, 25 millirems (0.00025 Sv) to the whole body, 75 millirems (0.00075 Sv) to the thyroid, and 25 millirems (0.00025 Sv) to any other organ of any member of the public from the uranium fuel cycle.

The NRC can also impose maximum activity discharge rates or concentration limits. Gaseous dose rates rather than effluent concentrations are generally used to calculate permissible rates for gaseous releases. The maximum permissible dose rates for gaseous releases are defined in ODCMs.

For liquid effluent discharges, a factor of 10 is applied to concentration limits defined in the regulations. The effluent concentration limits specified in 10 CFR Part 20 for identified nuclides, are used to calculate permissible release rates and concentrations for liquid releases. Plant operators implement these requirements by defining and setting alarm set-points for effluent monitoring instrumentation, which when exceeded would stop releases.

The operator is also required by their operating licence to implement a programme for radioactive effluent controls and for monitoring the potential impact of radioactive effluents on the environment through a radiological environmental monitoring programme.

Solid waste generation

The NRC has established limits on the types of radioactive waste and the amount of radioactivity that may be packaged and shipped offsite for burial or disposal.

Non-radioactive discharges

NPDES permits have limits on the discharges that are either treatment technology based or water quality based. Treatment technology limits are based on federal treatment standards set out within 40 CFR Part 423. Water quality based limits are set by the state when drafting each permit renewal. For some pollutants such as chlorine, the EPA would include the more restrictive technology based and water quality based limits in the permit.

Water quality based limits are nearly always set at the final discharge point to the receiving water. Treatment technology limits can also be set at the final discharge, or can be set at in-plant treatment systems. Federal NPDES rules prohibit meeting technology based limits by dilution.

Limits set for nuclear power plants are primarily expressed as concentrations in the same way that the federal treatment standards are expressed. Water quality based limits are usually expressed as both concentrations and kg/day pollutant loads.

The EPA can set limits of detection in the permit if it chooses, but it is usually not considered necessary. NPDES permits require the use of federally approved test methods/analytical methods (40 CFR Part 136), which have associated detection limits. Where some approved methods do not have detection limits, the EPA can set either test methods or detection limits in the permit (e.g. chlorine and bromine discharges from the Perry-1 plant).

4.6 Mexico

4.6.1 Regulatory regime

The National Commission on Nuclear Safety and Safeguards (CNSNS) is a semi-autonomous body in charge of nuclear regulation and safeguards, under the authority of the Ministry of Energy. The generation of electricity by nuclear means is the responsibility of the Federal Electricity Commission (CFE). Reporting of discharges at nuclear facilities is required on an annual and semi-annual basis, including quarterly information.

4.6.2 Demonstration of optimisation

Discharges are required to be optimised; however BATs are not used when determining discharge levels, although different techniques are evaluated on the basis of the lowest values for environmental discharges. There is not a policy in force to encourage the generation of one waste type over another waste type. In setting radioactive discharge authorisations, occupational exposures, the protection of the environment and decommissioning seem not to be considered within the optimisation process. Further clarity is advisable on this point in future in order to confirm existing arrangements.

4.6.3 Monitoring and management of discharges to the environment

Radioactive discharges

At the present time, both dose limits (5 mSv/year for the reference group at the site boundary) and activity limits (of total discharge at the site boundary) are used (IAEA 2010). Limits apply to the site as a whole, regardless of the number of facilities that are on that site. For nuclear power plants, the limits are based on annual and quarterly limits. The discharge authorisations are periodically renewed, on average every 2 years.

Both effluent and environmental monitoring are required from all sites for total activity, not specific radionuclides, although limits of detection are specified for particulates, tritium and radioactive iodine (IAEA 2010).

Solid waste generation

The main type of solid radioactive waste produced at the Laguna Verde nuclear power plants is low level waste, which is treated, conditioned and stored within the site boundaries.

Disposable solid radioactive waste (e.g. contaminated clothing, rags, paper and redundant laboratory equipment) are compressed into 200 litre drums. The liquids, solid slurries and spent filter cartridges are solidified into 200 litre drums, while the spent resins, filter sludges and concentrates are packaged into high integrity containers (HICs). A lack of space for storing the generated solid radioactive waste is driving the need to look into alternative technologies for minimising waste generation and reducing volume.

The CFE has responsibility for the management of radioactive wastes arising from Laguna Verde nuclear power plant, including their disposal. Radioactive waste is treated, conditioned and temporarily stored onsite (Barcenas and Mejia 1999).

Non-radioactive discharges

Regulations governing the use of chemicals in Mexico are particularly challenging to deconstruct due to multiple laws and regulations which overlap. Within the time available for this study, more information could not be found relating to the management of non-radioactive or chemical discharges from nuclear power plants in Mexico.

5 Data sources

The operators and regulators of the selected predecessor BWRs were contacted and information on discharges from the relevant power station reactors was requested and processed as described in section 3. The list of contacted operators and regulators is provided in Appendix A, Table A2.

There was a varied response from those operators and regulators contacted, but predominantly the data sources for radioactive gaseous and liquid discharges have been publicly available, either held within accessible databases or summarised in annual reports (e.g. radiation protection reports). Table 5.1 presents a summary of the data sources.

Aside from the USA, where the information is readily publicly available, obtaining information on non-radioactive discharges has proved more difficult, as responses from the operators often detail radioactive discharges only. There has been a mixed response from the operators or regulators for solid waste data.

When reviewing the available data there are differences in the way the discharge data is presented between countries. For example, some combine radionuclides into their respective groups while others report individual radionuclides. The US reactors use curies (Ci) to measure and report the radioactivity of discharges, and this differs from the SI unit of measure of radioactivity, the becquerel (Bq), used in Europe.

These differences in reporting make it more difficult to compare initial information and led to the need for some further data manipulation, which within the constraints of this study could only be partially completed.

There is also evidence that there is variation in the manipulation of the data as provided to the researchers, where some datasets have already been normalised, to take into account electrical output, whereas other datasets have not (or no information has been provided to state otherwise).

The data provided within Appendices B and C details discharges and waste generated for a three-year period (2010, 2011 and 2012). The development and presentation of a more complete dataset using data which has been obtained from beyond this timeframe could not be concluded due to the limited time available for this pilot study.

Table 5.1 Summary of data sources

(a) Europe and Mexico

Reactor	Contact (operator and regulator)	Response	Data source
Cofrentes (Spain)	Iberdrola	Yes	Cofrentes Environmental Statement
	Consejo de Seguridad Nuclear (CSN)	Yes	CSN Council Report: Nuclear Safety Congress Deputies and the Senate 2010, 2011, 2012
Leibstadt (Switzerland)	Kernkraftwerk Leibstadt AG	No	-
	Swiss Federal Nuclear	Yes	ENSI radiation protection reports 2010, 2011, 2012
Forsmark NPP 3 (Sweden)	Forsmarks Kraftgrupp ABB	Yes	Operational data radiation protection reports 2010, 2011, 2012
	SSM	Yes	Interpretation data for radiation protection reports and outage information
Laguna Verde NPP 2 (Mexico)	Comisión Federal de Electricidad	No	-
	National Commission on Nuclear Safety and Safeguards (CNSNS)	No	-

(b) USA

Reactor	Contact (operator and regulator)	Response	Data source
Clinton-1	Exelon Generation Co., LLC	Yes	Annual radioactive effluents release reports on NRC website
	Nuclear Regulatory Commission (NRC)	No	-
	Illinois Environmental Protection Agency (EPA)	Yes	Discharge monitoring reports (DMRs) for non-radiological liquid discharges
Grand Gulf-1	Entergy Nuclear Operations, Inc.	No	Annual radioactive effluents release reports on NRC website
	Nuclear Regulatory Commission (NRC)	No	-
LaSalle-1 and -2	Exelon Generation Co., LLC	Yes	Annual radioactive effluents release reports on NRC website
	Nuclear Regulatory Commission (NRC)	No	-
	Illinois Environmental Protection Agency (EPA)	Yes	Discharge monitoring reports (DMRs) for non-radiological liquid discharges
Limerick-1 and -2	Exelon Generation Co., LLC	Yes	Annual radioactive effluents release reports on NRC website
	Nuclear Regulatory Commission (NRC)	No	-
	Pennsylvania Department of Environmental Protection	No	Discharge monitoring reports (DMRs) for non-radiological liquid discharges
Nine Mile Point-2	Exelon Generation Co., LLC	Yes	Annual radioactive effluents release reports on NRC website
	Nuclear Regulatory Commission (NRC)	No	-
	New York Department of Environmental Conservation (NPDES Permit Program)	No	Discharge monitoring reports (DMRs) for non-radiological liquid discharges
Perry-1	FirstEnergy Nuclear Operating Co.	No	Annual radioactive effluents release reports on NRC website
	Nuclear Regulatory Commission (NRC)	No	-
	Ohio Environmental Protection Agency (EPA)	Yes	Discharge monitoring reports (DMRs) for non-radiological liquid discharges for last 10 years

(c) Japan

Reactor	Contact (operator and regulator)	Response	Data source
Fukushima II NPP (Daiichi)	Tokyo Electric Power Company (TEPCO)	No	-
	Nuclear Regulation Authority	Yes	JNES 2013 report: operational status of nuclear facilities in Japan
	Fukushima Prefecture Environmental Monitoring Centre	No	-
Hamaoka NPP Unit 5 (ABWR)	Chubu Electric Power Company	No	-
	Nuclear Regulation Authority	Yes	JNES 2013 report: operational status of nuclear facilities in Japan
	Shizuoka Prefecture Environmental Monitoring Centre	No	-
Kashiwazaki-Kariwa NPP Units 4 and 7	Tokyo Electric Power Company (TEPCO)	No	-
	Nuclear Regulation Authority	Yes	JNES 2013 report: operational status of nuclear facilities in Japan
	Niigata Prefecture Environmental Monitoring Centre	No	-
Shika NPP Units 1 and 2	Hokuriku Electric Power Company	No	-
	Nuclear Regulation Authority	Yes	JNES 2013 report: operational status of nuclear facilities in Japan
	Ishikawa Prefecture Environmental Monitoring Centre	No	-

6 Candidate reactors discharge data

This section describes the discharge data obtained from the final 23 candidate reactors.

These are described in sections for each country as follows:

- Section 6.1 European plants
- Section 6.2 Japanese plants
- Section 6.3 US plants

Note: No data has yet been obtained for the plant in Mexico.

The data presented has been taken at face value as obtained during the course of this study. In some cases there are uncertainties as to the exact meaning and application. Such uncertainties need to be addressed in future research.

6.1 European plants

6.1.1 Cofrentes nuclear power plant, Spain

Of the European reactors within this study, Cofrentes proved to yield the full range of data required: radioactive discharges (gaseous and liquid), non-radioactive discharges and solid waste generation. The data sources were annual CSN council reports and the 2012 Cofrentes Environmental Statement, both of which were publicly available.

Radioactive gaseous and liquid discharges are reported annually, as shown in Table 6.1, and are not broken down further into individual radionuclides as there are no nuclide-specific discharge limits given for Cofrentes (OSPAR 2012).

The data is presented in Appendix B, Tables B1 and B2.

Table 6.1 Reported gaseous and liquid radionuclides at Cofrentes nuclear power plant

Reported gaseous radionuclides	Reported liquid radionuclides
Carbon-14	Carbon-14
Tritium	Total dissolved gases (excluding tritium)
Noble gases	Dissolved gases
Halogens	
Particulates	

An extensive range of non-radioactive liquid discharges are reported monthly (in tonnes), as shown in the 2012 Environmental Statement for Cofrentes and in Appendix C, Table C1. However, the four most frequently used chemicals in Cofrentes are sulphuric acid, sodium hydroxide, sodium hypochloride and poly-aluminium chloride, as shown in Table 6.2, which contains further information regarding their use. The chemical discharge data available has been normalised in relation to gross electric production to achieve a measure of chemical use per megawatt hour (MWh) of electricity produced and is presented in Appendix C, Table C2.

Table 6.2 Most frequently used chemicals associated with reactor operations at Cofrentes

Chemical	Use
Sulphuric acid	Additive to the circulating water system, regulating pH
Sodium hydroxide	Regenerate the ion exchange resins/beds used in the production of demineralised water
Sodium hypochloride	Biocide in the water circulation systems, essential service water and wastewater
Poly-aluminium chloride	Coagulant aid in the pre-treatment of water

Solid waste generated by Cofrentes is reported annually, divided into three waste categories: non-hazardous, hazardous and low level waste/intermediate level waste combined. Similar to the quantity of chemicals used, the quantity of solid waste generated has also been normalised in relation to gross electric production to achieve a measure of solid waste production per megawatt hour (MWh) of electricity produced. This data is presented in Appendix B, Table B10.

No further operational information (such as outage timetables or frequency of fuel failures) was provided beyond what could be obtained from the CSN Council Reports and the 2012 Environmental Statement; therefore no judgements on whether the data is representative of 'normal' operations can be made at this point.

6.1.2 Leibstadt nuclear power plant, Switzerland

The ENSI radiation protection reports for 2010, 2011 and 2012 provided radioactive gaseous and liquid discharge data for individual radionuclides (15 radionuclides for gaseous and 6 radionuclides for liquid along with total alpha), see Appendix B, Tables B3 and B4. The provision of individual radionuclides activities is perhaps related to the fact that, unlike Spain, Switzerland has annual discharge limits for the release of tritium and other nuclides. However, the regulator does not require iodine-129 activity emissions to be measured.

No solid waste or non-radioactive discharge data was obtained for Leibstadt. No further operational information or metadata was provided to supplement the discharge data obtained.

6.1.3 Forsmark nuclear power plant 3, Sweden

The response from the operator, a radiation protection manager and the contact at the SSM yielded the most information from the European reactor search. Along with the provision of annual radiation protection reports from 2003 to 2012 which are not publicly available, the contacts also provided operational/metadata relating to fuel failures and outage periods.

A summary of the contextual data provided is given in Table 6.3.

Table 6.3 Contextual data provided by the Swedish regulatory authority SSM

Year	Fuel damage and outage periods
2010	Outage 12 September – 2 November Energy availability factor 81.4% In January, fuel damage first detected in October 2009 developed into secondary damage and fuel was removed during a short shutdown between 9 and 15 April In May another fuel damage event was detected, and in June there were signs of secondary damage. There was a shutdown between 29 June and 6 July to remove the damaged fuel In November, fuel damage was detected Summary: Due to the fuel damaged during the year there were increased emissions of xenon-133 and halogens. There were also increased aerosol emissions during the year probably due to pool decontamination following control rod cutting
2011	Outage 4 September – 16 October Energy availability factor 85.4% A short shutdown in April to remove damaged fuel
2012	Outage 8 July – 28 July Energy availability factor 93.1%

The annual radiation protection reports for 2010, 2011 and 2012 provided radioactive gaseous and liquid discharge data for an extensive number of individual radionuclides (32 radionuclides for gaseous and 16 radionuclides for liquid).

The reporting of such a large number of radionuclide activities may be due to the fact that although no radionuclide-specific discharge limits are defined by SSM, specific release-to-dose factors for each radionuclide discharged have to be calculated (97 radionuclides discharged to the marine environment and 159 radionuclides emitted to air) and therefore the data is readily available in this format prior to dose calculation. Data for Forsmark nuclear power plant 3 is presented in Appendix B, Tables B5 and B6.

No solid waste or non-radioactive discharge data was obtained for the Forsmark nuclear power plant 3.

6.2 Japanese plants

At the time of writing, no response has been forthcoming from the Japanese nuclear operators. The research phase of the pilot study identified a number of information sources (Chubu Electric Power Co. 2014, Hokuriku Electric Power Company 2014, TEPCO 2014a, 2014b) which appear to present real-time monitoring data. However, given the language barrier, it is not possible to establish with certainty whether the data is discharge related or general environmental radiation monitoring. It is also noted that each regional authority (or prefectural government) provides online radiation data. The

NRA provided a response in part to the information request including direction to reports written mainly in Japanese.

Because of the constraints of the pilot study it has not been possible to establish the reporting requirements placed upon the nuclear operators. For non-radioactive discharges to the environment, no information was obtained. In relation to radioactive discharges to the environment, guidance documentation (NSC 2001c) suggests the target radionuclides and minimum monitoring frequency as shown in Table 6.4.

It is important to note that these are understood to be reporting limits and do not relate to 'end of pipe' monitoring discharge limits. They are understood to relate to a reporting limit, below which there is no requirement for the operator to report to the regulator.

This information and data has been presented as provided by the Japanese Nuclear Safety Commission (NSC) and represents an area of uncertainty of understanding which needs to be addressed in the future.

Table 6.4 Target radionuclides for monitoring at Japanese nuclear power plants

Discharge state	Physical properties	Target radionuclides	Reporting limit (Bq/cm^3)	Minimum monitoring frequency
Airborne	Gaseous volatiles	Radioactive noble gases	2×10^{-2}	Continuous
		Iodine-131	7×10^{-9}	Weekly
		Iodine-133	7×10^{-8}	Monthly
		Tritium	4×10^{-5}	Weekly
	Particulates	Gamma emitters such as chromium-51, manganese-54, iron-59, cobalt-60, caesium-134 and caesium-137	4×10^{-9}	Weekly
		Strontium-89 and strontium-90	4×10^{-10}	Quarterly
		Total beta activity	4×10^{-9}	Monthly
		Total alpha activity	4×10^{-10}	Monthly
Liquid	-	Gamma emitters such as chromium-51, manganese-54, iron-59, cobalt -58, cobalt-60, iodine-131, caesium-134 and caesium-137	2×10^{-2}	Weekly or at every discharge
		Strontium-89 and strontium-90	7×10^{-4}	Quarterly
		Tritium	2×10^{-1}	Monthly
		Total beta activity	4×10^{-2}	Monthly
		Total alpha activity	4×10^{-3}	Monthly

Source: NSC (2001c)

The publicly available data presented noble gases and iodine-131 only for gaseous discharges (JNES 2013). As for liquid discharges, the publicly available data is reported in two forms. One is with tritium, but gives no indication as to what other radionuclides are present in the discharge, and one for tritium discharges only (JNES

2013). This data is presented in Appendix B, Table B7, and is obtained from the plants in accordance with NSC guidance (NSC 2001c).

In summary, it remains unclear as to how the Japanese nuclear operators report their discharges to the environment given the presence of prescribed dose limits and absence of actual discharge values. Similarly, it is unclear as to what they are legally required to report. There may be some overlap with radiological safety and environment safety which may be explained by cultural differences in the reporting of radiological discharges to the environment.

6.3 US plants

6.3.1 General information for US plants

Radioactive discharges

Gaseous radioactive wastes are generated from gases or airborne particulates vented from reactor and turbine equipment containing radioactive material.

Liquid radioactive wastes are generated from liquids received directly from portions of the reactor coolant system or where contaminated by contact with liquids from the reactor coolant system.

Solid radioactive wastes comprise solids from the reactor coolant system, solids from contact with reactor coolant system liquids or gases, or solids used in the steam and power conversion system.

US nuclear power plant operators are required to provide within their annual radioactive effluent reports a summation of all airborne and liquid waste releases, grouped into the radionuclide categories.

For gaseous wastes the reported radionuclide categories are fission and activation gases (noble gases), tritium, carbon-14, iodines and radionuclides in particulate form with radioactive half-lives greater than 8 days.

For liquid wastes the reported radionuclide categories are fission and activation gases (noble gases), tritium, and dissolved and entrained gases (xenon-133, xenon-135, xenon-138, krypton-87, krypton-88), and gross alpha radioactivity. Volumes of waste released and volumes of dilution water used during the monitoring period are also reported.

It is believed that up until 2010/11 there were no requirements for nuclear plant operators to report on carbon-14 releases. Since this time, the NRC has recommended that plant operators evaluate whether carbon-14 is a principal radionuclide, and, if so, using the methodology set out in EPRI (2010), estimate and report the amount of carbon-14 released.

The total number of curies (Ci) of each radionuclide present in gaseous and liquid releases for each quarter are reported. For the purposes of this study, all discharge data has been converted from Ci to becquerels (Bq) and presented in Appendix B, Tables B8 and B9.

If a radionuclide was not present at a level greater than or equal to the lower limit of detection (LLD) then the value is expressed as <LLD. The LLD is expressed as microcuries per cubic centimetre ($\mu Ci/cm^3$).

For radioactive liquid wastes, both total releases and average diluted concentrations of specific radionuclides are presented.

Liquid releases are expressed as a percentage of the ODCM limits. The data is compared against the relevant ODCM limits and expressed as a percentage of the respective limits. For dissolved and entrained noble gases, the concentration is limited to 2×10^{-4} microcuries per millilitre total activity (µCi/ml).

The NRC has introduced a policy to make all nuclear power plants zero radioactive liquid release plants. As a result, some of the candidate reactor plants have not had planned liquid releases for several years.

Federal and state regulations also specify reporting requirements following accidental releases of radioactivity.

Website locations for data on radioactive discharges from US plants are given in Appendix A, Table A3.

Solid waste generation

Solid waste generated by candidate US reactors is split into three waste categories: Class A, Class B and Class C wastes. The following waste types are reported annually:

- spent resins, filter sludges, evaporator bottoms;
- dry compactable waste, contaminated equipment;
- irradiated components, control rods etc.;
- other wastes (water and oil, filters).

The candidate BWR operators report on the number of radioactive waste shipments over the reporting period and provide information on the characterisation of the solid radioactive waste shipped offsite including container volumes for Class A, B and C wastes, total curie quantity, estimations of the major radionuclides composition by type of waste (% abundance), source of waste and processing employed, container type and solidification agent or absorbent.

Non-radioactive discharges

Contact details and website locations for data on non-radioactive discharges from US plants are given in Appendix A, Table A4.

6.3.2 General abatement techniques used in US plants

Details of the liquid and gaseous treatment systems and solid waste management systems were obtained for US BWRs from their respective environmental impact statements (where these were available) on the NRC website database. The types of treatment systems used are generally very similar across all candidate reactors, a summary of which is provided below.

Radioactive gaseous waste management systems

Gaseous waste management systems generally include an off-gas system, standby gas treatment system, various building ventilation systems and monitored release points, and radioactive waste/reactor building vents.

For the majority of the candidate reactors, a separate and independent gaseous radioactive waste off-gas system is installed.

The off-gas systems collect, contain and process the non-condensable radioactive gases extracted from the steam condenser. The condenser off-gases are the largest source of radioactive gaseous waste. Gases are exhausted by the steam jet air ejectors and flow through a preheater to a catalytic recombiner, where the hydrogen is recombined with oxygen to form steam. After recombination, the off-gas is routed to chillers to remove moisture, and is then passed through activated carbon adsorber vessels. The activated carbon selectively adsorbs and delays the noble fission product gases, which have short half-lives, for decay. After exiting a carbon bed filter, the gases pass through a HEPA filter where any entrained particulates or any activated carbon dusts are collected. Then, along with dilution make-up air, the waste gases continue to the respective vent or stack for discharge to the environment.

Continuous sampling for noble gases, particulates and iodines is generally performed at each release point.

Other sources of radioactive gases are from the reactor enclosures, the turbine enclosures and radioactive waste buildings. Discharges of these gases are planned, monitored and controlled, and the gases are discharged through dedicated release points. Standby gas treatment systems and reactor enclosure recirculation systems are used to reduce radioactive levels before being discharged into the environment.

Radioactive liquid waste management systems

Liquid waste management systems are composed of subsystems designed to collect and treat different types of liquid waste. These subsystems are generally designated as the equipment drain processing subsystem (clean radioactive waste), floor drain processing subsystem (dirty radioactive waste), chemical waste subsystem and miscellaneous supporting subsystems.

Radioactive liquid wastes can be processed for packaging and shipping offsite, returned to the condensate system, or mixed with cooling tower blowdown and discharged to the environment in batch modes through dedicated discharge points. All releases are sampled and analysed before release to ensure radionuclide concentrations are within the specified limits.

The concentration of radioactive material released in liquid effluents to unrestricted areas is limited to 10 times the effluent concentrations specified in 10 CFR Part 20 for radionuclides other than dissolved or entrained noble gases.

The control of liquid releases from the liquid radioactive waste system includes radiation monitors, effluent flow control valves and dilution water flow rate monitoring equipment.

Liquid waste tanks are analysed for principal gamma emitters prior to release.

Solid waste management

Solid waste management systems collect, process and package solid radioactive wastes for storage and offsite shipment and permanent disposal. Wet wastes are generally collected, dewatered, packaged in containers and stored before offsite shipment. Dry wastes usually consist of small tools, air filters, miscellaneous paper, rags, equipment parts that cannot be effectively decontaminated, wood and solid laboratory waste.

Non-radiological liquid wastes

Industrial wastewater, cooling water and stormwater discharges are governed by the relevant NPDES permits. NPDES permits set effluent quality limits and monitoring requirements for the plant's discharges. Treated liquid non-radioactive liquid waste is generally diluted cooling tower blowdown and is batch discharged into the receiving environment. Releases are sampled and monitored to check compliance with the specified limits in 10 CFR Part 20.

6.3.3 Specific plants

Clinton-1

The Clinton-1 station consists of a GE BWR 6 and is located 37 km south-east of Bloomington, Illinois. It is operated by Exelon Generation Co., LLC and the reactor started commercial operation in 1987. The discharge data presented in Appendix B, Tables B8 and B9, relates to a single reactor core, Clinton-1.

For noble gases, iodines and particulates, the average flow rates for each release point are averaged over the duration of the sampling period and these results, along with specific isotopic concentrations, are then used to determine the total activity released during the time period in question.

Tritium releases are calculated for each release point from the measured tritium concentration, the volume of the sample, the tritium collection efficiency and the respective stack exhaust flow rates.

There were no abnormal or unplanned liquid or gaseous releases from 2010 to 2012.

During 2010, 2011 and 2012 gaseous releases were well within the legal limits. There were no liquid effluent releases during this period. The last liquid release from the plant occurred in September 1992.

No further operational information was obtained such as outage timetables or frequency of fuel failures.

Grand Gulf-1

The Grand Gulf-1 station consists of a GE BWR 6 and is located 32 km south of Vicksburg, Mississippi. It is operated by Entergy Nuclear Operations Inc. and the reactor started commercial operation in 1985. The discharge data presented in Appendix B, Tables B8 and B9, relates to a single core reactor, Grand Gulf-1.

There were no abnormal or unplanned liquid or gaseous releases from 2010 to 2012.

Liquid effluents were released in batch mode during the reporting period. The number of releases and time of batches is reported for each quarter and total annual releases are also reported.

No further operational information was obtained such as outage timetables or frequency of fuel failures.

LaSalle-1 and -2

The LaSalle station consists of two GE BWR 5 units and is located about 18 km south-east of Ottawa, Illinois. It is operated by Exelon Generation Co., LLC with both reactors starting commercial operation in 1984. The discharge data presented in Appendix B, Tables B8 and B9, relates to both reactor cores, LaSalle-1 and -2.

Release points (containment vent and purge system, main vent stack, standby gas treatment system) are continuously monitored for principal gamma emitters and tritium. Batch release tanks are sampled for principal gamma emitters, iodine-131, dissolved and entrained noble gases, tritium, gross alpha, strontium-89, strontium-90 and iron-55.

During 2010, 2011 and 2012 gaseous releases were within the legal limits.

In 2010 there were two abnormal gaseous batch releases made from the plant with a total activity release of 7.18×10^{-3} Ci (2.66×10^{8} Bq). One release was due to the cycled condensate tank, where some of the leaked tritiated water was observed to have evaporated during remediation activities. Estimations concluded that 2.0×10^{-1} Ci (7.4×10^{9} Bq) of tritium was released as a result of this leak with no tritium found to have migrated offsite.

Limerick-1 and -2

The Limerick station consists of two GE BWR 4 units and is located about 34 km north-west of Philadelphia, Pennsylvania. It is operated by Exelon Generation Co., LLC with Limerick-1 starting commercial operation in 1986 and Limerick-2 in 1990. The discharge data presented in Appendix B, Tables B8 and B9, relates to both reactor cores, Limerick-1 and -2.

Waste gases from the off-gas system are released to the turbine enclosure vent stack and diluted with air and monitored on release through the north stack.

Liquid wastes are processed for packaging and offsite shipment, returned to the condensate system, or mixed with cooling tower blowdown and released from the plant into the Schuylkill River with radionuclide concentrations below specified limits. The processed waste is collected in one of two sample tanks, which are normally reused, but if necessary, it is treated or discharged into the Schuylkill River.

The total activity concentration for all dissolved or entrained gases is limited to less than 2×10^{-4} picocuries/ml (pCi/ml).

2010

There was one planned liquid release in December 2010 that resulted in about 1,800 litres of contaminated water being released from the overflow of a turbine enclosure sample sink to a drain that discharges to the Limerick Hold Pond. Samples were analysed for tritium, gamma and hard-to-detect analytes. The dose from this release was calculated as: 6.89×10^{-5} millirem (6.89×10^{-10} Sv) for a teenager liver and 6.01×10^{-5} millirem (6.01×10^{-10} Sv) for an adult-total body.

There were two gaseous releases from the emergency service water pipe tunnel during a planned outage in March through April 2010. Cobalt-60 was identified on the continuous air monitoring particulate filters for those two periods.

There were a number of abnormal batch releases in 2010. Total activity released from liquid releases was 9.43×10^{-3} Ci (3.49×10^{8} Bq). Total activity released from gaseous discharges was 8.70×10^{-8} Ci (3.22×10^{3} Bq).

2011

There were a number of planned liquid batch releases in 2011 and one planned gaseous batch release in 2011.

In June 2011 a planned outage on the Unit 1 B turbine enclosure HVAC exhaust fans was performed. No noble gas, particulate, iodine or tritium activity was identified. The maximum activity of 21,000 pCi/l was recorded. The source of the tritium was thought to be groundwater movement from the 2009 turbine building leak. Tritium activity over a period of months returned to below the minimum detectable concentration of 3,500 pCi/l.

During March through April 2011, effluent iodine samples identified detectable concentrations of iodine-131. A total of 32.48 μCi (1.20×10^6 Bq) of iodine-131 was released through these vents. No other samples collected during 2011 showed positive iodine-131 activity. This activity was probably related to the events of March 2011 at the nuclear power plant at Fukushima, Japan, and the associated trans-Pacific transportation of airborne releases.

There were no abnormal batch releases in 2011.

2012

There were a number of abnormal liquid and gaseous batch releases from the plant in 2012. The total activity from abnormal liquid releases in 2012 was 2.48×10^{-1} Ci (9.18×10^9 Bq). The total activity from gaseous abnormal discharges in the same period was 3.10×10^{-4} Ci (1.15×10^7 Bq).

In March 2012 a tank of contaminated water was released via the approved pathway to the Schuylkill River. An initial sample taken showed only tritium, at a concentration of 112,000 pCi/l. The maximum daily organ dose from the release was 0.175 millirem (1.80×10^{-6} Sv) to a child liver. The maximum daily total body dose to a child was 0.123 millirem (1.20×10^{-6} Sv).

Non-radioactive liquid waste

Non-radiological liquid waste discharges are governed by a Pennsylvania Department of Environmental Protection (PADEP) issued NPDES permit and regulated under PADEP's regulations.

Nine Mile Point-2

The Nine Mile Point station consists of two GE BWR units, Nine Mile Point-2 is a GE BWR 5. The station is located approximately 8 km north-east of Oswego, New York, on the shore of Lake Ontario. It is operated by Constellation Energy Nuclear Group LLC (CENG) and owned by Exelon Generation Co., LLC and EDF. The reactors began commercial operation in 1969 and 1988 respectively. The discharge data presented in Appendix B, Tables B8 and B9 relates to both reactor cores together, Nine Mile Point-1 and -2.

Each reactor unit is provided with a separate and independent gaseous radioactive waste/off-gas system and separate release stack.

Liquid waste batches are either solidified and stored until they can be disposed, or if they meet the release limits, they are released to Lake Ontario with cooling water discharges through the discharge bay of each unit. The liquid waste system in Unit 2 is completely independent of the system in Unit 1 except for laundry waste. All potentially radioactive liquid waste discharges from each unit are routed through a separate line to the discharge bay.

There were no identified unplanned or abnormal releases during the period 2010 to 2012.

Perry-1

The Perry-1 station consists of a GE BWR 6 and is located about 56 km north-east of Cleveland, Ohio. It is operated by FirstEnergy Nuclear Operating Company and the reactor started commercial operation in 1987. The discharge data presented in Appendix B, Tables B8 and B9, relates to a single reactor core, Perry-1.

Gaseous effluents are discharged via one of four effluent vents. Each of these four effluent vents contains radiation detectors that continuously monitor the air to ensure that the levels of radioactivity released are below regulatory limits.

There were no identified unplanned or abnormal releases during the period 2010 to 2012.

Susquehanna-1 and -2

The Susquehanna station consists of two GE BWR 4 units and is located about 113 km north-east of Harrisburg, Pennsylvania. It is operated by PPL Susquehanna LLC with Susquehanna-1 starting commercial operation in 1983 and Susquehanna-2 in 1985. The discharge data presented in Appendix B, Tables B8 and B9, relates to both reactor cores, Susquehanna-1 and -2.

All effluents are released to the atmosphere from one of the five rooftop vents located on the reactor and turbine buildings for each unit and the standby gas treatment system in the radioactive waste building. Continuous sampling for particulates and iodines is performed at each vent as well as continuous monitoring for noble gases.

The processing methods used for liquid wastes include filtration and/or demineralisation. All liquid effluents are released in batch mode and sampled and analysed before release. The effluent is discharged into the cooling tower blowdown line for dilution prior to release to the Susquehanna River.

There were no identified unplanned or abnormal releases during the period 2010 to 2012.

6.4 Summary and conclusions

A summary of the data provided in sections 6.1 to 6.3 is given in Table 6.5.

Table 6.5 Summary of data obtained and status: BWR research project pilot study

Reactor/site	Air radiological discharges	Water radiological discharges	Solid waste radiological discharges	Non-radiological discharges	Operational discharges
Cofrentes	✓	✓	✓	✓	X
Leibstadt	✓	✓	X	X	X
Forsmark	✓	✓	X	X	✓ (1)
Fukushima II (Daiichi)	✓	✓	✓	X	X
Hamaoka	✓	✓	✓	X	X
Kashiwazaki- Kariwa	✓	✓	✓	X	X
Shika	✓	✓	✓	X	X
Clinton	✓	✓	+	+	X
Grand Gulf	✓	✓	+	X	X
LaSalle-1, -2	✓	✓	+	+	✓ (1)
Limerick-1, -2	✓	✓	+	+	✓ (1)
Nine Mile Point-1, 2	✓	✓	+	X	X (2)
Perry-1	✓	✓	+	+	X (2)
Susquehanna-1, -2	✓	✓	+	X	X (2)
Laguna Verde	X	X	X	X	X

Key

Tick indicates data obtained and presented in this report.
Cross indicates no data obtained in project timescale, some may still arrive (e.g. for Japan), or will require further research.
Plus indicates some data obtained but requires reworking and processing before can be reported and assessed.
(1) Operational data obtained, needs further examination to assess suitability for comparison with discharge data.
(2) No specific operational/abnormal data identified, but information obtained inconclusive and further research needed.

7 Recommendations

This initial pilot study provides a review of the discharge and solid waste data available for predecessor BWRs.

There are a number of aspects of the work commenced during this pilot study which it has not been possible to complete, but which are important to enable the Environment Agency to realise the project objectives. These should be addressed as part of a new study.

This new study would return to and reactivate contacts, refresh the data and sources and would comprise further work on current data, access further data, interpret and develop this data to inform the vision for the eventual outcome of the project, and inform the wider context.

The recommendations for such future work are proposed below:

Further work on current data and accessing further data

- Further manipulation of the discharge data and in-depth analysis using operational information.
- Conduct a gap analysis on the data already obtained and seek to address these gaps through further contact with operators. Obtain further contextual data from operators, as the metadata is as important as the actual discharge data (such as outages, fuel failure and normalisation information) and relate this to the discharge data obtained.
- An aspect which is currently considered to be important is the further investigation of discharge trends (ideally over a 10-year period).
- Focus data collection on a smaller number of reactors/stations where significant reliable data has already been obtained, to build a complete picture of all relevant aspects.

Interpretation of data and development of 'ideal' metrics

- Interpret the data for a smaller number of stations to better understand the relationship between power generation, discharges, operation etc., to enable data normalisation and key metrics to be developed.
- Use these key metrics, develop a template for future data collection and processing to enable comparisons between reactors to be made.

Further work to inform the wider context

- Understand cultural differences between territories which may result in difference in aspects such as nomenclature, basis of limits (monitoring/measurement or calculation) and quality assurance for monitoring and dose calculations for regulator or licensee.
- Establish whether regulators have data repositories for discharge information similar to the ELGA database where all CSN's liquid and gaseous data is stored for Spanish nuclear power plants. If so, investigate the likelihood of obtaining access to this data.

- Develop a better understanding of the principle of optimisation in relation to discharges to the environment for chosen territories and how the proposals for optimisation demonstrate best available techniques (BAT).
- An element of demonstrating the implementation of BAT involves the consideration of costs relating to the abatement technologies used. This information was not available within the timeframe of the pilot study; however, cost data should be part of the scope of further work.
- Further research the regulatory function of the NRA in Japan, to better understand its future approach to discharge limit setting and the management/abatement of non-radiological discharges to the environment.
- Establish the chosen treatment methods and waste packages to manage radioactive solid waste from BWRs. This is important to enable waste forecasting to ensure that the UK has adequate provision of treatment plants and interim storage facilities.
- Informed by the outcome of these further investigations, formulate some conclusions on potential discharge restrictions for the proposed UK ABWRs.

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List of abbreviations

ABWR	advanced boiling water reactor
ALARA	as low as reasonably achievable
ALARP	as low as reasonably practicable
BAT	best available techniques
BWR	boiling water reactor
CFE	Federal Electricity Commission (Mexico)
CFR	Code of Federal Regulations (USA)
CNSNS	National Commission on Nuclear Safety and Safeguards (Mexico)
CSN	Consejo de Seguridad Nuclear (Nuclear Safety Council, Spain)
DMR	discharge monitoring report
ENSI	Swiss Federal Nuclear Safety Inspectorate
EPA	Environmental Protection Agency (USA)
HEPA	high-efficiency particulate air
IAEA	International Atomic Energy Agency
JAEA	Japanese Atomic Energy Authority
JNES	Japan Nuclear Energy Safety Organisation
LLD	lower limit of detection
LWTS	liquid waste treatment system
METI	Ministry of Economics, Trade and Industry (Japan)
MoE	Ministry of the Environment (Japan)
NSC	Nuclear Safety Commission (Japan)
NPDES	National Pollutant Discharge Elimination System (USA)
NPP	nuclear power plant
NRA	Nuclear Regulation Authority (Japan)
NRC	Nuclear Regulatory Commission (USA)
ODCM	offsite dose calculation manual
OSPAR	Convention for the Protection of the Marine Environment of the North-East Atlantic
SSM	Swedish radiation safety authority
SWTS	solid waste treatment system

Appendix A: Contact and data source details

Table A1: List of BWRs currently operational world-wide with the candidate predecessor BWRs chosen for this study highlighted in green

No.	BWR Power Station	Country	Location	Owner/Operator	Date Operating	Size (MWt & MWe (net))		Reactor Type / Model	Fuel type
						MWt	MWe		
1	Browns Ferry Nuclear Power Plant Unit 1	US	32 miles W of Huntsville, AL	Tennessee Valley Authority	1974	3458	1101	BWR 4	uranium dioxide pellets made from slightly enriched uranium (uranium dioxide (UO2))
2	Browns Ferry Nuclear Power Plant Unit 2	US	32 miles W of Huntsville, AL	Tennessee Valley Authority	1975	3458	1104	BWR 4	uranium dioxide pellets made from slightly enriched uranium.
3	Browns Ferry Nuclear Power Plant Unit 3	US	32 miles W of Huntsville, AL	Tennessee Valley Authority	1977	3458	1105	BWR 4	uranium dioxide pellets made from slightly enriched uranium.
4	Brunswick Nuclear Generating Station Unit 1	US	40 miles S of Wilmington, NC	Progress Energy (Carolina Power & Light Co.)	1977	2923	938	BWR 4	slightly enriched uranium dioxide (U02).
5	Brunswick Nuclear Generating Station Unit 2	US	40 miles S of Wilmington, NC	Progress Energy (Carolina Power & Light Co.)	1975	2923	920	BWR 4	slightly enriched uranium dioxide (U02).
6	Clinton Nuclear Generating Station Unit 1	US	23 miles SSE of Bloomington, IL	Exelon Generation Co., LLC	1987	3473	1065	BWR 6	slightly enriched uranium dioxide (U02).
7	Columbia Nuclear Generating Station	US	20 miles NNE of Pasco, WA	Energy Northwest	1984	3486	1170	BWR 5	slightly enriched (less than 5% by weight) uranium dioxide pellets.
8	Cooper Nuclear Station	US	23 miles S of Nebraska City, NE	Nebraska Public Power District	1974	2419	768	BWR 4	low-enriched high density ceramic uranium dioxide fuel pellets.
9	Dresden Nuclear Power Plant Unit 2	US	25 miles SW of Joliet, IL	Exelon Generation Co., LLC	1970	2957	883	BWR 3	low-enriched uranium dioxide with enrichments of 5 percent by weight uranium-235.
10	Dresden Nuclear Power Plant Unit 3	US	25 miles SW of Joliet, IL	Exelon Generation Co., LLC	1971	2957	850	BWR 3	
11	Duane Arnold Energy Centre	US	8 miles NW of Cedar Rapids, IA	Next Era Energy Duane Arnold, LLC	1975	1912	601	BWR 4	slightly enriched (less than 5 weight percent) uranium dioxide pellets.
12	Fermi Nuclear Generating Station Unit 2	US	25 miles NE of Toledo, OH	DTE Energy Electric Company	1988	3430	1037	BWR 4	slightly enriched uranium dioxide (U02).
13	FitzPatrick Nuclear Power Plant	US	6 miles NE of Oswego, NY	Entergy Nuclear Operations, Inc.	1975	2536	813	BWR 4	slightly enriched uranium dioxide pellets.

No.	BWR Power Station	Country	Location	Owner/Operator	Date Operating	Size (MWt & MWe (net))		Reactor Type / Model	Fuel type
						MWt	MWe		
14	Grand Gulf Nuclear Generating Station Unit 1	US	20 miles S of Vicksburg, MS	Entergy Nuclear Operations, Inc.	1985	4,408	1266	BWR 6	low-enrichment (less than 5% by weight) high-density ceramic uranium dioxide fuel.
15	Hatch Nuclear Generating Station Unit 1	US	20 miles S of Vidalia, GA	Southern Nuclear Operating Co., Inc.	1975	2804	876	BWR 4	slightly enriched (currently 3.8 percent uranium-235 by weight, with an anticipated increase to 4.2 percent by weight) uranium dioxide in the form of high-density ceramic pellets.
16	Hatch Nuclear Generating Station Unit 2	US	20 miles S of Vidalia, GA	Southern Nuclear Operating Co., Inc.	1979	2804	883	BWR 4	
17	Hope Creek Nuclear Generating Station Unit 1	US	18 miles SE of Wilmington, DE	PSEG Nuclear, LLC	1986	3840	1172	BWR 4	low-enriched uranium-dioxide fuel with enrichments to a nominal 5.0 percent by weight uranium-235.
18	LaSalle County Nuclear Generating Station Unit 1	US	11 miles SE of Ottawa, IL	Exelon Generation Co., LLC	1984	3546	1137	BWR 5	slightly enriched uranium dioxide (UD2).
19	LaSalle County Nuclear Generating Station Unit 2	US	11 miles SE of Ottawa, IL	Exelon Generation Co., LLC	1984	3546	1140	BWR 5	
20	Limerick Nuclear Power Plant Unit 1	US	21 miles NW of Philadelphia, PA	Exelon Generation Co., LLC	1986	3515	1130	BWR 4	enriched uranium.
21	Limerick Nuclear Power Plant Unit 2	US	21 miles NW of Philadelphia, PA	Exelon Generation Co., LLC	1990	3515	1134	BWR 4	
22	Monticello Nuclear Generating Plant Unit 1	US	35 miles NW of Minneapolis, MN	Northern States Power Company – Minnesota	1971	1775	578	BWR 3	low-enriched uranium-dioxide fuel with enrichments below 5.0 percent by weight Uranium-235.
23	Nine Mile Point Nuclear Generating Station Unit 1	US	6 miles NE of Oswego, NY	Nine Mile Point Nuclear Station, LLC (Constellation Energy)	1974	1850	621	BWR 2	uranium-dioxide fuel that is slightly enriched up to 4.95 percent by weight uranium-235.
24	Nine Mile Point Nuclear Generating Station Unit 2	US	6 miles NE of Oswego, NY	Constellation Energy Group Inc (CENG) (owned by Exelon and EDF)	1988	3988	1276	BWR 5	uranium-dioxide fuel that is slightly enriched up to 4.95 percent by weight uranium-235.
25	Oyster Creek Nuclear Generating Station	US	9 miles S of Toms River, NJ	Exelon Generation Co., LLC	1969	1930	619	BWR 2	uranium dioxide pellets. Fuel is enriched to no more than 5 percent.
26	Peach Bottom Nuclear Generating Station Unit 2	US	17.9 miles S of Lancaster, PA	Exelon Generation Co., LLC	1974	3514	1125	BWR 4	low enriched uranium dioxide with enrichments below 5 percent by weight uranium- 235.
27	Peach Bottom Nuclear Generating Station Unit 3	US	17.9 miles S of Lancaster, PA	Exelon Generation Co., LLC	1974	3514	1138	BWR 4	

No.	BWR Power Station	Country	Location	Owner/Operator	Date Operating	Size (MWt & MWe (net))		Reactor Type / Model	Fuel type
						MWt	MWe		
28	Perry Nuclear Generating Station Unit 1	US	35 miles NE of Cleveland, OH	FirstEnergy Nuclear Operating Co.	1987	3758	1240	BWR 6	slightly enriched uranium dioxide (UO).
29	Pilgrim Nuclear Generating Station	US	38 miles SE of Boston, MA	Entergy Nuclear Operations, Inc.	1972	2028	677	BWR 3	low-enriched uranium dioxide with maximum enrichments of 4.6% by weight uranium-235.
30	Quad Cities Nuclear Generating Station Unit 1	US	20 miles NE of Moline, IL	Exelon Generation Co., LLC	1973	2957	908	BWR 3	low-enriched uranium dioxide with enrichments below 5 percent by weight uranium-235.
31	Quad Cities Nuclear Generating Station Unit 2	US	20 miles NE of Moline, IL	Exelon Generation Co., LLC	1973	2957	911	BWR 3	
32	River Bend Nuclear Generating Station Unit 1	US	24 miles NNW of Baton Rouge, LA	Entergy Nuclear Operations, Inc.	1986	3091	967	BWR 6	slightly enriched uranium dioxide (UO).
33	Susquehanna Steam Electric Station Unit 1	US	70 miles NE of Harrisburg, PA	PPL Susquehanna, LLC	1983	3952	1257	BWR 4	low-enriched uranium dioxide fuel with enrichments below 5.0 percent by weight uranium-235.
34	Susquehanna Steam Electric Station Unit 2	US	70 miles NE of Harrisburg, PA	PPL Susquehanna, LLC	1985	3952	1257	BWR 4	
36	Fukushima II (Daini) Nuclear Power Plant 1	Japan	Naraha and Tomioka in the Futaba District of Fukushima Prefecture	Tokyo Electric Power Company (TEPCO)	1982	3293	1067	BWR 5	Enriched UO_2
37	Fukushima II (Daini) Nuclear Power Plant 2	Japan	Naraha and Tomioka in the Futaba District of Fukushima Prefecture	Tokyo Electric Power Company (TEPCO)	1984	3293	1067	BWR 5	Enriched UO_2
38	Fukushima II (Daini) Nuclear Power Plant 3	Japan	Naraha and Tomioka in the Futaba District of Fukushima Prefecture	Tokyo Electric Power Company (TEPCO)	1985	3293	1067	BWR 5	Enriched UO_2
39	Fukushima II (Daini) Nuclear Power Plant 4	Japan	Naraha and Tomioka in the Futaba District of Fukushima Prefecture	Tokyo Electric Power Company (TEPCO)	1987	3293	1067	BWR 5	Enriched UO_2
40	Hamaoka Nuclear Power Plant Unit 3	Japan	Omaezaki city, Shizuoka Prefecture, on Japan's east coast, 200 km south-west of Tokyo	Chubu Electric Power Company	1987	3293	1056	BWR 5	Enriched UO_2
41	Hamaoka Nuclear Power Plant Unit 4	Japan	Omaezaki city, Shizuoka Prefecture, on Japan's east coast, 200 km south-west of Tokyo	Chubu Electric Power Company	1993	3293	1092	BWR 5	Enriched UO_2 / MOX
42	Hamaoka Nuclear Power Plant Unit 5	Japan	Omaezaki city, Shizuoka Prefecture, on Japan's east coast, 200 km south-west of Tokyo	Chubu Electric Power Company	2005	3926	1325	ABWR	Enriched UO_2

No.	BWR Power Station	Country	Location	Owner/Operator	Date Operating	Size (MWt & MWe (net))		Reactor Type / Model	Fuel type
						MWt	MWe		
43	Higashidōri Nuclear Power Plant, A	Japan	Higashidōri in eastern Aomori Prefecture, on the Shimokita Peninsula, facing the Pacific Ocean	Tohoku Electric Power Company	2005	3293	1067	BWR 5	Enriched UO_2
44	Kashiwazaki-Kariwa Nuclear Power Plant 1	Japan	Kashiwazaki and Kariwa in Niigata Prefecture, Japan on the coast of the Sea of Japan	Tokyo Electric Power Company (TEPCO)	1985	3293	1067	BWR 5	Enriched UO_2
45	Kashiwazaki-Kariwa Nuclear Power Plant 2	Japan	Kashiwazaki and Kariwa in Niigata Prefecture, Japan on the coast of the Sea of Japan	Tokyo Electric Power Company (TEPCO)	1990	3293	1067	BWR 5	Enriched UO_2
46	Kashiwazaki-Kariwa Nuclear Power Plant 3	Japan	Kashiwazaki and Kariwa in Niigata Prefecture, Japan on the coast of the Sea of Japan	Tokyo Electric Power Company (TEPCO)	1993	3293	1067	BWR 5	Enriched UO_2 / MOX
47	Kashiwazaki-Kariwa Nuclear Power Plant 4	Japan	Kashiwazaki and Kariwa in Niigata Prefecture, Japan on the coast of the Sea of Japan	Tokyo Electric Power Company (TEPCO)	1994	3293	1067	BWR 5	Enriched UO_2
48	Kashiwazaki-Kariwa Nuclear Power Plant 5	Japan	Kashiwazaki and Kariwa in Niigata Prefecture, Japan on the coast of the Sea of Japan	Tokyo Electric Power Company (TEPCO)	1990	3293	1067	BWR 5	Enriched UO_2
49	Kashiwazaki-Kariwa Nuclear Power Plant 6 ABWR	Japan	Kashiwazaki and Kariwa in Niigata Prefecture, Japan on the coast of the Sea of Japan	Tokyo Electric Power Company (TEPCO)	1996	3926	1315	ABWR	Enriched UO_2
50	Kashiwazaki-Kariwa Nuclear Power Plant 7 ABWR	Japan	Kashiwazaki and Kariwa in Niigata Prefecture, Japan on the coast of the Sea of Japan	Tokyo Electric Power Company (TEPCO)	1997	3926	1315	ABWR	Enriched UO_2
51	Onagawa Nuclear Power Plant Unit 1	Japan	Onagawa in the Oshika District and Ishinomaki city, Miyagi Prefecture	Tohoku Electric Power Company	1984	1593	498	BWR 4	Enriched UO_2

No.	BWR Power Station	Country	Location	Owner/Operator	Date Operating	Size (MWt & MWe (net))		Reactor Type / Model	Fuel type
						MWt	MWe (net)		
52	Onagawa Nuclear Power Plant Unit 2	Japan	Onagawa in the Oshika District and Ishinomaki city, Miyagi Prefecture	Tohoku Electric Power Company	1995	2436	796	BWR 5	Enriched UO_2
53	Onagawa Nuclear Power Plant Unit 3	Japan	Onagawa in the Oshika District and Ishinomaki city, Miyagi Prefecture	Tohoku Electric Power Company	2002	2436	796	BWR 5	Enriched UO_2 / MOX
54	Shika Nuclear Power Plant Unit 1 BWR	Japan	Shika, Ishikawa, Japan	Hokuriku Electric Power Company	1993	1593	505	BWR 5	Enriched UO_2
55	Shika Nuclear Power Plant Unit 2 ABWR	Japan	Shika, Ishikawa, Japan	Hokuriku Electric Power Company	2006	3926	1108	ABWR	Enriched UO_2
56	Shimane Nuclear Power Plant Unit 1	Japan	Kashima-chou in the city of Matsue in the Shimane Prefecture	Chūgoku Electric Power Company.	1974	1380	439	BWR 3	Enriched UO_2
57	Shimane Nuclear Power Plant Unit 2	Japan	Kashima-chou in the city of Matsue in the Shimane Prefecture	Chūgoku Electric Power Company.	1989	2436	789	BWR 5	Enriched UO_2 / MOX
58	Tokai Nuclear Power Plant Unit 2	Japan	Ibaraki Prefecture	Japan Atomic Power Company (JAPC)	1978	3293	1060	BWR 5	Enriched UO_2
59	Tsuruga Nuclear Power Plant Unit 1	Japan	Tsuruga, Fukui Prefecture	Japan Atomic Power Company (JAPC)	1970	1070	340	BWR 2	Enriched UO_2
60	Olkiluoto Nuclear Power Plant Unit 1	Finland	Gulf of Bothnia in the municipality of Eurajoki in western Finland	Teollisuuden Voima (a subsidiary of Pohjolan Voima)	1979	2500	880	ABB BWR 2500	Low-enriched uranium - uranium dioxide UO2
61	Olkiluoto Nuclear Power Plant Unit 2	Finland	Gulf of Bothnia in the municipality of Eurajoki in western Finland	Teollisuuden Voima (a subsidiary of Pohjolan Voima)	1982	2500	880	ABB BWR 2500	

No.	BWR Power Station	Country	Location	Owner/Operator	Date Operating	Size (MWt & MWe (net))		Reactor Type / Model	Fuel type
						MWt	MWe (net)		
62	Gundremmingen Nuclear Power Plant Unit B	Germany	Gundremmingen, district of Günzburg, Bavaria	Kernkraftwerk Gundremmingen GmbH (KGG), a joint operation of RWE Power AG and E.ON Kernkraft GmbH	1984	3840	1284	BWR 72	
63	Gundremmingen Nuclear Power Plant Unit C	Germany	Gundremmingen, district of Günzburg, Bavaria	Kernkraftwerk Gundremmingen GmbH (KGG), a joint operation of RWE Power AG and E.ON Kernkraft GmbH	1985	3840	1288	BWR 72	
64	Tarapur Atomic Power Station Unit 1	India	Tarapur, Maharashtra	Nuclear Power Corporation of India LTD. (NPCIL)	1969	530	150	BWR 1	imported enriched uranium
65	Tarapur Atomic Power Station Unit 2	India	Tarapur, Maharashtra	Nuclear Power Corporation of India LTD. (NPCIL)	1969	530	150	BWR 1	
66	Laguna Verde Nuclear Power Plant Unit 1	Mexico	Gulf of Mexico, in Alto Lucero, Veracruz, Mexico	Comisión Federal de Electricidad (CFE), the national electric company owned by the Mexican government.	1990	2027	700	BWR 5	Uranium (U235 Isotope 3% enriched)
67	Laguna Verde Nuclear Power Plant Unit 2	Mexico	Gulf of Mexico, in Alto Lucero, Veracruz, Mexico	Comisión Federal de Electricidad (CFE), the national electric company owned by the Mexican government	1995	700	2027	BWR 5	Uranium (U235 Isotope 3% enriched)
68	Cofrentes Nuclear Power Plant	Spain	2 km southeast of Cofrentes, Spain	Iberdrola	1985	3237	1064	BWR 6	Enriched uranium
69	Forsmark Nuclear Power Plant F1	Sweden	Forsmark, Sweden	FKA, Subsidiary of Vattenfall	1980	2928	984	ABB BWR 75	This information could not be found
70	Forsmark Nuclear Power Plant F2	Sweden	Forsmark, Sweden	FKA, Subsidiary of Vattenfall	1981	2928	996	ABB BWR 75	
71	Forsmark Nuclear Power Plant F3	Sweden	Forsmark, Sweden	FKA, Subsidiary of Vattenfall	1985	3300	1170	ABB BWR 3000	This information could not be found

No.	BWR Power Station	Country	Location	Owner/Operator	Date Operating	Size (MWt & MWe (net))		Reactor Type / Model	Fuel type
						MWt	MWe		
72	Oskarshamn Nuclear Power Plant Unit 1	Sweden	30 km north of Oskarshamn directly at the Kalmarsund at the Baltic Sea coast	Operated by OKG (Oskarshamnsverkets Kraftgrupp) part of E.on Group (E.ON Sverige own 54.5%; Fortum own 45.5%)	1972	1375	473	ABB BWR	This information could not be found
73	Oskarshamn Nuclear Power Plant Unit 2	Sweden	30 km north of Oskarshamn directly at the Kalmarsund at the Baltic Sea coast	Operated by OKG (Oskarshamnsverkets Kraftgrupp) part of E.on Group (E.ON Sverige own 54.5%; Fortum own 45.5%)	1975	1800	638	ABB BWR	
74	Oskarshamn Nuclear Power Plant Unit 3	Sweden	30 km north of Oskarshamn directly at the Kalmarsund at the Baltic Sea coast	Operated by OKG (Oskarshamnsverkets Kraftgrupp) part of E.on Group (E.ON Sverige own 54.5%; Fortum own 45.5%)	1985	3900	1400	BWR 75	
75	Ringhals Nuclear Power Plant Unit 1	Sweden	Värö Peninsula (Swedish: Väröhalvön) in Varberg Municipality, 60 km south of Gothenburg	RAB (70% by Vattenfall and 30% by E.ON)	1976	2540	865	ABB BWR	
76	Leibstadt Nuclear Power Plant	Switzerland	Municipality Leibstadt (canton Aargau, Switzerland) on the Rhine River close of the Aare delta and the German border	Kernkraftwerk Leibstadt AG (KKL) (composed of six Swiss energy companies)	1984	3600	1190	BWR 6	This information could not be found
77	Mühleberg Nuclear Power Plant	Switzerland	Mühleberg municipality in the (Canton of Berne, Switzerland) north of the village of Mühleberg	BKW FMB Energie AG.	1972	1097	373	BWR 4	Uranium oxide rods

Table A2: Contact Log for the 23 predecessor reactors

Country	Reactor Name	Operator	Operator	Regulator	Date Letter & Questionnaire Sent		Follow-up contact made	
			Contact details	Contact details	Operator	Regulator	Operator	Regulator
US	Clinton-01	Exelon Generation Co., LLC	Kerr, Christopher J:(GenCo) christopher.kerr@exeloncorp.com	**NRC Contacts:** 'Richard.Conatser@nrc.gov' 'opa3.resource@nrc.gov' 'opa4.resource@nrc.gov' 'opa1.resource@nrc.gov' 'opa2.resource@nrc.gov' **EPA Contacts:** 'albert.ryan@epa.gov' 'danesi.robin@epa.gov' 'wilson.scott@epa.gov' **Regional EPA and State Authority Contacts (NPDES permitting offices):** New York - redraper@gw.dec.state.ny.us Illinois - al.keller@illinois.gov Ohio - paul.novak@epa.state.oh.us Pennsylvania - rfurlan@pa.gov	Emailed Exelon lead on 13/02/2014	Emailed NRC on 04/03/2014 Emailed EPA 05/03/14	Yes	Sufficient information was obtained for this scoping study from publicly available sources (mainly NRC effluents database and EPA NPDES databases, where available).
US	LaSalle County Nuclear Generating Station Unit 1	Exelon Generation Co., LLC						
US	LaSalle County Nuclear Generating Station Unit 2	Exelon Generation Co., LLC						
US	Limerick Nuclear Power Plant Unit 1	Exelon Generation Co., LLC						
US	Limerick Nuclear Power Plant Unit 2	Exelon Generation Co., LLC						
US	Nine Mile Point Nuclear Generating Station Unit 2	Constellation Energy Group Inc (CENG) (owned by Exelon and EDF)						
US	Grand Gulf Nuclear Generating Station Unit 1	Entergy Nuclear Operations, Inc.					No (declined to provide information for the study)	
US	Perry Nuclear Generating Station Unit 1	FirstEnergy Nuclear Operating Co.	Jennifer Young - 'jyoung@firstenergycorp.com		Only contact details available on website was for media officer - Called this person on 04/03/2014 and sent follow-up email.			
US	Susquehanna Steam Electric Station Unit 1	PPL Susquehanna, LLC	Joe Scopelliti Community Relations Manager Tel: 1-866-832-4474 jjscopelliti@pplweb.com		Called Community Relations Manage for PPL on 04/03/2014 and sent follow-up email. Stated they will forward to BWR Working Group for consideration.			
US	Susquehanna Steam Electric Station Unit 2	PPL Susquehanna, LLC						

Country	Reactor Name	Details of Responses Received		Additional Contacts
		Operator	Regulator	
US	Clinton-01	Response received on 21/02/14 - directed to published discharge data on NRC effluents database on the website. Very useful information was provided on regulation of radiological and non radiological discharges from nuclear plants. Further information was provided on Exelons new ABWR in South Texas and directed to the Environmental Statement on the NRC site. Follow-up email sent on 25/02/14- Requested confirmation on suitability of candidate Exelon operated BWRs. Response received on 28/02/14 - confirming suitability of candidate BWRs. Noted that BWR6 is predecessor to ABWR design and should focus on Japanese ABWRs for data.	No response received from NRC. Responses were received from the following Regional EPA/State Authorities: - Illinois EPA - Sharon Dowson, Sharon.Dowson@Illinois.gov (11/03/2014) - provided NPDES permits for Clinton-01 and LaSalle-1 & -2. Directed to DMR data for each BWR: http://dataservices.epa.illinois.gov/dmrdata/default.aspx - Ohio EPA - Eric Nygaard, Eric.Nygaard@epa.ohio.gov on (19/03/2014) - provided general information on how Ohio EPA regulates non-radiological discharges, provided non-radiological liquid discharge data for Perry-01 BWR. Directed to NPDES permit on website: http://www.epa.ohio.gov/dsw/permits/npdes_info.aspx	
US	LaSalle County Nuclear Generating Station Unit 1			
US	LaSalle County Nuclear Generating Station Unit 2			
US	Limerick Nuclear Power Plant Unit 1			
US	Limerick Nuclear Power Plant Unit 2			
US	Nine Mile Point Nuclear Generating Station Unit 2			
US	Grand Gulf Nuclear Generating Station Unit 1	Declined to provide any further information for the study. Information for this BWR was obtained from publicly available sources.		
US	Perry Nuclear Generating Station Unit 1	No response received. All information for this BWR was obtained from publicly available sources.		
US	Susquehanna Steam Electric Station Unit 1	No response received. All information for this BWR was obtained from publicly available sources.		
US	Susquehanna Steam Electric Station Unit 2			

Country	Reactor Name	Operator	Operator	Regulator	Date Letter & Questionnaire Sent		Follow-up contact made	
			Contact details	Contact details	Operator	Regulator	Operator	Regulator
Spain	Cofrentes Nuclear Power Plant	Iberdrola (IBERDROLA GENERACIÓN NUCLEAR S.A.)	Patricia Corrons pcorrons@iberdrola.es (Valencia Region) (emailed 04.03.2014)	comunicaciones@csn.es (emailed 04.03.2014) (0034) 91 346 01 00 (from the 'contact' section of CSN)	Emailed 04.03.2014.	Emailed 04.03.2014.	N/A	11/03/2014
Sweden	Forsmark Nuclear Power Plant F3	FKA, Subsidiary of Vattenfall	eva.hyden@forsmark.vattenfall.se.- contact for FKA environmental issues +46173 – 81957	registrator@ssm.se. Stefan.appelgren@gov.se (Ministry of Environment), contact found on IAEA Country Profile	Emailed 03.03.14	Emailed 03.03.14 & 13.03.14	N/A	N/A
Switzerland	Leibstadt Nuclear Power Plant	Kernkraftwerk Leibstadt AG (KKL) (composed of six Swiss energy companies)	Tel.: +41 (0)56 267 72 50 (Information Centre)	info@ensi.ch	An AMEC colleague rang the Information Centre number and was able to get the following email address for someone who may be able to help: wilfried.kaufmann@kkl.ch (obtained 06/03/2014)	Emailed 04.03.2014	Emailed wilfried.kaufmann@kkl.ch on 06.03.14 Out of the Office until 17.03.14	N/A
Mexico	Laguna Verde Nuclear Power Plant Unit 2	Comisión Federal de Electricidad (CFE), the national electric company owned by	eneas.herrera@cfe.gob.mx (found on a powerpoint presentation when googled CFE Laguna Verde)	Jaime Aguirre Gómez, jaguirre@cnsns.gob.mx	Emailed 06.03.2014	Emailed 06.03.2015	Yes	Yes

Country	Reactor Name	Details of Responses Received		Additional Contacts
		Operator	Regulator	
Spain	Cofrentes Nuclear Power Plant	Carlos Gomez replied 06.03.2014 with information on CSN reports :http://www.csn.es/index.php/es/periodicas/informes-al-congreso-y-el-senado Annual Reports from ENRESA Waste Management http://www.enresa.es/busquedade/publicaciones_y_audiovisuales/documentacion?pag=1&orden=anio General Radioactive Waste Plan : http://www.enresa.es/files/multimedios/6PGRR_Espa_ol_Libro_versi_n_indexada.pdf Technical information: http://www.cncofrentes.es/wcofrnts/corporativa/iberdrola?IDPAG=ESCOFPREPUB&WT.ac=PUBLICACIONES Monthly reports: http://www.cncofrentes.es/wcofrnts/corporativa/iberdrola?IDPAG=ESCOFCONINF&codCache=13940916250776618	Responded with an email stating they could not provide any more detailed information other than that publicly available. In case of additional or future requests of a similar nature, they need a prior formal notification from a public British body, preferably their UK homologous the ONR.	
Sweden	Forsmark Nuclear Power Plant F3	Staffan Hennigor (Rad Protection Manager) replied with annual reports on effluent discharge (2002-2012) along with information about liquid and aerial discharges and operating philosophy.	Charlotte Lager responded (14.03.2013) providing the same reports as Staffan Hennigor but, crucially, along with really helpful interpretation data and info on fuel failures.	Non-radioactive discharges is handled by the County Administrative Board in Uppsala County. http://www.lansstyrelsen.se/uppsala/En/Pages/default.aspx uppsala@lansstyrelsen.se This information came from Charlotte Lager (at SSM) on 20.03.14
Switzerland	Leibstadt Nuclear Power Plant	No information provided	Radiation protection reports, Financial reports regarding incidents, Annual reports on nuclear safety	
Mexico	Laguna Verde Nuclear Power Plant Unit 2	No information provided	No information provided	

Country	Reactor Name	Operator	AMEC	Operator	Regulator	Date Letter & Questionnaire		Follow-up contact made	
				Contact details	Contact details	Operator	Regulator	Operator	Regulator
Japan	Fukushima II (Daini) Nuclear Power Plant 2	Tokyo Electric Power Company (TEPCO)	NH	Mr Junichi Suzuki, Nuclear Power Management Dept., szk.junichi@tepco.co.jp	gence@pref.fukushima.jp	05.03.14	Environmental / radiation monitoring centre - 04.03.14. NRA - 06.03.14	No response at present	Response received
Japan	Fukushima II (Daini) Nuclear Power Plant 4	Tokyo Electric Power Company (TEPCO)	NH	Mr Junichi Suzuki, Nuclear Power Management Dept., szk.junichi@tepco.co.jp	gence@pref.fukushima.jp	05.03.14	Environmental / radiation monitoring centre - 04.03.14. NRA - 06.03.14	No response at present	Response received
Japan	Hamaoka Nuclear Power Plant Unit 5	Chubu Electric Power Company	NH	shirai.kazushi@chuden.co.jp	radiation@pref.shizuoka.lg.jp	05.03.14	Environmental / radiation monitoring centre - 04.03.14. NRA - 06.03.14	No response at present	Response received
Japan	Kashiwazaki-Kariwa Nuclear Power Plant 4	Tokyo Electric Power Company (TEPCO)	NH	Mr Junichi Suzuki, Nuclear Power Management Dept., szk.junichi@tepco.co.jp	ngt000130@pref.niigata.lg.jp	05.03.14	Environmental / radiation monitoring centre - 05.03.14. NRA - 06.03.14	No response at present	Response received
Japan	Kashiwazaki-Kariwa Nuclear Power Plant 5	Tokyo Electric Power Company (TEPCO)	NH	Mr Junichi Suzuki, Nuclear Power Management Dept., szk.junichi@tepco.co.jp	ngt000130@pref.niigata.lg.jp	05.03.14	Environmental / radiation monitoring centre - 05.03.14. NRA - 06.03.14	No response at present	Response received
Japan	Kashiwazaki-Kariwa Nuclear Power Plant 6 ABWR	Tokyo Electric Power Company (TEPCO)	NH	Mr Junichi Suzuki, Nuclear Power Management Dept., szk.junichi@tepco.co.jp	ngt000130@pref.niigata.lg.jp	05.03.14	Environmental / radiation monitoring centre - 05.03.14. NRA - 06.03.14	No response at present	Response received

Country	Reactor Name	Details of Responses Received		Additional Contacts
		Operator	Regulator	
Japan	Fukushima II (Daini) Nuclear Power Plant 2	N/A	Response received from NRA on 18.03.14. Majority of questions answered with direction to mainly Japanese written documents.	**Regulator:** Little confidence in a response due to generic nature of regulator email address. Emailed local environmental / radiation monitoring centre 04.03.14. Emailed NRA mailbox on 06.03.14. Response received 18.03.14 - NH replied 18.03.14. **Operator:** Internet search yielded no plant or company contact details. Contacted company on their London number (020 7629 5271) and given contact details (matsumura.takeshi@tepco.co.uk) of a person who may be able to help. Mr Takeshi forwarded our request for information to Mr Junichi Suzuki at the Nuclear Power Management Dept.
Japan	Fukushima II (Daini) Nuclear Power Plant 4	N/A	Response received from NRA on 18.03.14. Majority of questions answered with direction to mainly Japanese written documents.	**Regulator:** Little confidence in a response due to generic nature of regulator email address. Emailed local environmental / radiation monitoring centre 04.03.14. Emailed NRA mailbox on 06.03.14.Response received 18.03.14 - NH replied 18.03.14. **Operator:** Internet search yielded no plant or company contact details. Contacted company on their London number (020 7629 5271) and given contact details (matsumura.takeshi@tepco.co.uk) of a person who may be able to help. Mr Takeshi forwarded our request for information to Mr Junichi Suzuki at the Nuclear Power Management Dept.
Japan	Hamaoka Nuclear Power Plant Unit 5	N/A	Response received from NRA on 18.03.14. Majority of questions answered with direction to mainly Japanese written documents.	**Regulator:** Little confidence in a response due to generic nature of regulator email address. Emailed local environmental / radiation monitoring centre - 04.03.14. Emailed NRA mailbox on 06.03.14.Response received 18.03.14 - NH replied 18.03.14. **Operator:** Internet search yielded no plant or company contact details. Contacted company on their London number (020 7408 0801) and given contact email address of a person who may be able to help. London contact forwarded on request for information to colleagues in Japan.
Japan	Kashiwazaki-Kariwa Nuclear Power Plant 4	N/A	Response from Niigata Prefecture environmental / radiation monitoring centre on 13.03.14 stating that Niigata Prefectural Govt. not able to provide appropriate answers and recommended to contact NRA. Response received from NRA on 18.03.14. Majority of questions answered with direction to mainly Japanese written documents.	**Regulator:** Little confidence in a response due to generic nature of regulator email address. Emailed local environmental / radiation monitoring centre 05.03.14. Response 13.03.14 stating that Niigata Prefectural Govt. not able to provide appropriate answers. Recommended to contact NRA who have already been contacted. Emailed NRA mailbox on 06.03.14. Response received 18.03.14 - NH replied 18.03.14. **Operator:** Internet search yielded no plant or company contact details. Contacted company on their London number (020 7629 5271) and given contact details (matsumura.takeshi@tepco.co.uk) of a person who may be able to help. Mr Takeshi forwarded our request for information to Mr Junichi Suzuki at the Nuclear Power Management Dept.
Japan	Kashiwazaki-Kariwa Nuclear Power Plant 5	N/A	Response from Niigata Prefecture environmental / radiation monitoring centre on 13.03.14 stating that Niigata Prefectural Govt. not able to provide appropriate answers and recommended to contact NRA. Response received from NRA on 18.03.14. Majority of questions answered with direction to mainly Japanese written documents.	**Regulator:** Little confidence in a response due to generic nature of regulator email address. Emailed local environmental / radiation monitoring centre 05.03.14. Response 13.03.14 stating that Niigata Prefectural Govt. not able to provide appropriate answers. Recommended to contact NRA who have already been contacted. Emailed NRA mailbox on 06.03.14. **Operator:** Internet search yielded no plant or company contact details. Contacted company on their London number (020 7629 5271) and given contact details (matsumura.takeshi@tepco.co.uk) of a person who may be able to help. Mr Takeshi forwarded our request for information to Mr Junichi Suzuki at the Nuclear Power Management Dept.
Japan	Kashiwazaki-Kariwa Nuclear Power Plant 6 ABWR	N/A	Response from Niigata Prefecture environmental / radiation monitoring centre on 13.03.14 stating that Niigata Prefectural Govt. not able to provide appropriate answers and recommended to contact NRA. Response received from NRA on 18.03.14. Majority of questions answered with direction to mainly Japanese written documents.	**Regulator:** Little confidence in a response due to generic nature of regulator email address. Emailed local environmental / radiation monitoring centre 05.03.14. Response 13.03.14 stating that Niigata Prefectural Govt. not able to provide appropriate answers. Recommended to contact NRA who have already been contacted. Emailed NRA mailbox on 06.03.14.Response received 18.03.14 - NH replied 18.03.14. **Operator:** Internet search yielded no plant or company contact details. Contacted company on their London number (020 7629 5271) and given contact details (matsumura.takeshi@tepco.co.uk) of a person who may be able to help. Mr Takeshi forwarded our request for information to Mr Junichi Suzuki at the Nuclear Power Management Dept.

Country	Reactor Name	Operator	Operator	Regulator	Date Letter & Questionnaire		Follow-up contact made	
			Contact details	Contact details	Operator	Regulator	Operator	Regulator
Japan	Kashiwazaki-Kariwa Nuclear Power Plant 7 ABWR	Tokyo Electric Power Company (TEPCO)	Mr Junichi Suzuki, Nuclear Power Management Dept., szk.junichi@tepco.co.jp	ngt000130@pref.niigata.lg.jp	05.03.14	Environmental / radiation monitoring centre - 05.03.14. NRA - 06.03.14	No response at present	Response received
Japan	Shika Nuclear Power Plant Unit 1 BWR	Hokuriku Electric Power Company	pub-mast@rikuden.co.jp	e170700@pref.ishikawa.lg.jp	05.03.14	Environmental / radiation monitoring centre - 05.03.14. NRA - 06.03.14	No response at present	Response received
Japan	Shika Nuclear Power Plant Unit 2 ABWR	Hokuriku Electric Power Company	pub-mast@rikuden.co.jp	e170700@pref.ishikawa.lg.jp	05.03.14	Environmental / radiation monitoring centre - 05.03.14. NRA - 06.03.14	No response at present	Response received

Country	Reactor Name	Details of Responses Received		Additional Contacts
		Operator	Regulator	
Japan	Kashiwazaki-Kariwa Nuclear Power Plant 7 ABWR	N/A	Response from Niigata Prefecture environmental / radiation monitoring centre on 13.03.14 stating that Niigata Prefectural Govt. not able to provide appropriate answers and recommended to contact NRA. Response received from NRA on 18.03.14. Majority of questions answered with direction to mainly Japanese written documents.	**Regulator:** Little confidence in a response due to generic nature of regulator email address. Emailed local environmental / radiation monitoring centre 05.03.14. Response 13.03.14 stating that Niigata Prefectural Govt. not able to provide appropriate answers. Recommended to contact NRA who have already been contacted. Emailed NRA mailbox on 06.03.14.Response received 18.03.14 - NH replied 18.03.14. **Operator:** Internet search yielded no plant or company contact details. Contacted company on their London number (020 7629 5271) and given contact details (matsumura.takeshi@tepco.co.uk) of a person who may be able to help. Mr Takeshi forwarded our request for information to Mr Junichi Suzuki at the Nuclear Power Management Dept.
Japan	Shika Nuclear Power Plant Unit 1 BWR	N/A	Response received from NRA on 18.03.14. Majority of questions answered with direction to mainly Japanese written documents.	Little confidence in a response due to generic nature of regulator and operator email addresses. Internet search yielded no operator contact details. **Regulator:** Emailed local environmental / radiation monitoring centre 05.03.14. Emailed NRA mailbox on 06.03.14. Response received 18.03.14 - NH replied 18.03.14. **Operator:** Internet search yielded no specific operator contact details. Emailed mailbox on operators 'english' website' 05.03.14.
Japan	Shika Nuclear Power Plant Unit 2 ABWR	N/A	Response received from NRA on 18.03.14. Majority of questions answered with direction to mainly Japanese written documents.	Little confidence in a response due to generic nature of regulator and operator email addresses. **Regulator:** Emailed local environmental / radiation monitoring centre 05.03.14. Emailed NRA mailbox on 06.03.14. Response received 18.03.14 - NH replied 18.03.14. **Operator:** Internet search yielded no specific operator contact details. Emailed mailbox on operators 'english' website' 05.03.14.

Table A3 Additional Web Site Details for US Annual Radioactive Effluent Release Report

Site	Web Address
Clinton-01	http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-specific-reports/clin.html
Grand Gulf-1	http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-specific-reports/gg1.html
LaSalle-1 & 2	http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-specific-reports/lasa1-2.html
Limerick-1 & 2	http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-specific-reports/lim1-2.html
Nine Mile Point - 1	http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-specific-reports/nmp1-2.html
Perry-1	http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-specific-reports/perr1.html
Susquehanna-1 & 2	http://www.nrc.gov/reactors/operating/ops-experience/tritium/plant-specific-reports/susq1-2.html

Table A4 Contact Details and Data Sources for US Non Radioactive Discharges

Non-radiological liquid discharges monitoring data			
Reactor Name	**EPA/Other Authority**	**Location of Discharge Monitoring Reports (DMRs)**	**Other Information Provided**
Perry-1	Ohio EPA	10 years of DMR data provided in raw data file	NPDES Permit: http://www.epa.ohio.gov/dsw/permits/npdes_info.aspx
Clinton-1	Illinois EPA	NPDES DMR data: http://dataservices.epa.illinois.gov/dmrdata/default.aspx	NPDES Permit: Illinois Environmental Protection Agency - http://www.epa.state.il.us/water/permits/waste-water/index.html
La Salle -1 &2		Select how you want to search (NPDES permit ID Or NPDES permit name). From the dropdowns displayed select the permitted entity you are interested in as well as the monitoring year. There is also an option provided to export data as a *.csv file. The NPDES number for Clinton is IL0036919; the NPDES number for LaSalle is IL0048151.	
Grand Gulf-1	Mississippi Department of Environmental Quality	eDMR https://etempo.deq.state.ms.us/eTempoWeb/Login	
Limerick -1 & -2	Pennsylvania Department of Environmental Protection	NPDES eDMR Data System http://www.ahs.dep.state.pa.us/NRS/broker.exe?_service=tim&_program=nrs101.nrs101e.sas	
Susquehanna - 1 & -2	Susquehanna River Basin Authority	http://www.srbc.net/	

Appendix B: Radioactive discharge data

Table B1: Reported radioactive discharges to air from **Cofrentes NPP**, 2010-2012

Operational Performance				Year	Releases to air, Bq				
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)		C-14	H-3	Noble gas	Halogen	Particulate
Cofrentes	1984	1064	3237	2010	3.60E+11	6.03E+11	1.82E+13	1.20E+10	1.45E+08
				2011	4.21E+11	1.05E+12	1.76E+13	1.08E+10	1.15E+08
				2012	2.29E+11	4.89E+11	7.58E+12	2.49E+08	1.06E+07
				Mean	3.37E+11	7.14E+11	1.45E+13	7.68E+09	9.02E+07

Data source: CSN Council Report: Nuclear Safety Congress Deputies and the Senate 2010, 2011 & 2012 (found at https://www.csn.es/index.php/es/periodicas/informes-al-congreso-y-el-senado). IAEA PRIS (last updated 2014)

Table B2: Reported radioactive liquid discharges for **Cofrentes NPP**, 2010-2012

Operational Performance				Year	Releases to water, Bq		
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)		Total (Excluding dissolved gases and H-3)	H-3	Dissolved gases
Cofrentes	1984	1064	3237	2010	9.42E+07	1.88E+11	1.29E+07
				2011	1.67E+08	2.35E+11	6.89E+07
				2012	6.47E+07	3.29E+11	1.22E+06
				Mean	1.09E+08	2.51E+11	2.77E+07

Data source: CSN Council Report: Nuclear Safety Congress Deputies and the Senate 2010, 2011 & 2012 (found at https://www.csn.es/index.php/es/periodicas/informes-al-congreso-y-el-senado). IAEA PRIS (last updated 2014)

Table B3: Reported radioactive discharges to air from **Leibstadt NPP**, 2010-2012

Operational Performance				Year	Releases to air, Bq								
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)		C-14 (CO2)	H-3	Kr-87	Xe-133	Xe-135	Xe-135m	Xe-138	I-131	Mn-54
Leibstadt	1984	1220	3600	2010	5.60E+11	2.90E+12		1.60E+10	2.70E+10	2.20E+09	1.10E+09	5.60E+07	1.60E+06
				2011	5.70E+11	1.60E+12		2.20E+10	5.30E+10	1.50E+10		6.10E+07	9.00E+05
				2012	6.40E+11	1.20E+12	6.40E+08	1.10E+11	2.30E+10			3.50E+07	5.90E+05
				Mean	5.90E+11	1.90E+12	6.40E+08	4.93E+10	3.43E+10	8.60E+09	1.10E+09	5.07E+07	1.03E+06

Operational Performance				Year	Releases to air, Bq						
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)		Co-58	Co-60	Sr-89	I-131 (aerosol)	Ba-140	La-140	Total α
Leibstadt	1984	1220	3600	2010	1.20E+05	2.60E+06		1.80E+06	3.20E+05	3.50E+05	7.20E+04
				2011	7.70E+04	2.60E+06		3.30E+06	7.90E+05	5.30E+05	1.60E+05
				2012		2.30E+06	1.30E+05	1.40E+06	2.30E+05	3.60E+04	9.90E+03
				Mean	9.85E+04	2.50E+06	1.30E+05	2.17E+06	4.47E+05	3.05E+05	8.06E+04

Data source: ENSI Radiation Protection Reports 2010, 2011, 2012. Publicly available data which can be found at http://www.ensi.ch/de/2013/06/21/strahlenschutzbericht-2012-ensi-an-8302/ . IAEA PRIS (last updated 2014)

Table B4: Reported radioactive liquid discharges for **Leibstadt NPP**, 2010-2012

Operational Performance				Year	Releases to water, Bq						
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)		H-3	Cr-51	Mn-54	Co-58	Co-60	Zn-65	Total α
Leibstadt	1984	1220	3600	2010	4.10E+12		3.30E+07	1.00E+07	1.40E+08	3.10E+07	6.10E+05
				2011	2.00E+12		9.70E+06	3.10E+06	6.40E+07	1.20E+07	3.30E+05
				2012	1.40E+12	7.30E+06	8.70E+06	2.70E+06	8.20E+07	2.70E+07	3.20E+05
				Mean	2.50E+12	7.30E+06	1.71E+07	5.27E+06	9.53E+07	2.33E+07	4.20E+05

Data source: ENSI Radiation Protection Reports 2010, 2011, 2012. Publicly available data which can be found at http://www.ensi.ch/de/2013/06/21/strahlenschutzbericht-2012-ensi-an-8302/ . IAEA PRIS (last updated 2014)

Table B5: Reported radioactive discharges to air from **Forsmark NPP 3**, 2010-2012

Operational Performance				Year	Releases to air, Bq												
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)		C-14OX	H-3OX	Ar-41	Kr-85	Kr-85m	Kr-87	Kr-88	Kr-89	Xe-131m	Xe-133	Xe-133m	Xe-135	Xe-135m
Forsmark NPP 3	1985	1170	3300	2010	7.42E+11	3.22E+11	2.09E+11		8.98E+09	9.61E+10	1.35E+11	3.47E+10	8.79E+10	2.77E+12	1.04E+11	2.91E+11	3.80E+11
				2011	6.70E+11	3.00E+11	6.40E+09	2.60E+11		1.20E+11				6.90E+12	1.00E+11	9.90E+11	8.20E+11
				2012	6.40E+11	3.00E+11	9.20E+09	1.80E+09		2.80E+10				4.60E+11		2.00E+11	3.40E+11
				Mean	6.84E+11	3.07E+11	7.49E+10	1.31E+11	8.98E+09	8.14E+10	1.35E+11	3.47E+10	8.79E+10	3.38E+12	1.02E+11	4.94E+11	5.13E+11

Operational Performance				Year	Releases to air, Bq												
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)		Xe-137	Xe-138	I-131	I-133	Cr-51	Mo-99	Mn-54	Co-58	Co-60	Nb-95	U-235	Pu-238	Pu-239
Forsmark NPP 3	1985	1170	3300	2010	6.46E+11	6.65E+11	2.37E+08	1.17E+08	1.05E+07		4.27E+06	1.17E+07	3.67E+07			1.51E+03	1.65E+03
				2011	2.40E+12	1.50E+11	5.30E+08	1.60E+08	7.70E+06	1.10E+06	1.60E+06	5.40E+06	1.90E+07		7.80E+02	2.70E+03	
				2012	1.50E+12	2.20E+11	3.10E+07	7.50E+07			1.20E+06	8.10E+05	1.60E+07	4.00E+05	1.00E+03	6.40E+03	
				Mean	1.52E+12	3.45E+11	2.66E+08	1.17E+08	9.10E+06	1.10E+06	2.36E+06	5.97E+06	2.39E+07	4.00E+05	8.90E+02	3.54E+03	1.65E+03

Operational Performance				Year	Releases to air, Bq					
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)		Pu-239 + Pu-240	Am-241	Am-243	Cm-242	Cm-243	Cm-244
Forsmark NPP 3	1985	1170	3300	2010			7.50E+04	6.93E+02		
				2011	3.60E+03	1.70E+02	1.30E+05	1.40E+03	3.50E+00	8.70E+02
				2012	1.20E+03	4.00E+02	1.70E+05	7.90E+02	1.60E+00	3.90E+02
				Mean	2.40E+03	2.85E+02	1.25E+05	9.61E+02	2.55E+00	6.30E+02

Data source for: Radiation Protection Reports 2010, 2011, 2012 (not publicly available therefore provided by Forsmark Radiation Protection Manager and the Swedish Regulator, SSM). IAEA PRIS (last updated 2014)

Table B6: Reported radioactive liquid discharges for **Forsmark NPP 3**, 2010-2012

Operational Performance				Year	Releases to water, Bq								
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)		H-3	Co-60	Ni-63	Cs-134	Cs-137	Ce-141	U-235	U-238	Pu-238
Forsmark NPP 3	1985	1170	3300	2010	5.23E+11	1.23E+06		7.43E+06	1.61E+07				1.90E+05
				2011	5.80E+11	1.10E+06	6.20E+05	3.70E+06	1.20E+07	5.80E+04	8.20E+02	2.60E+03	2.40E+03
				2012	3.40E+11	3.70E+06	1.00E+05	8.40E+05	8.20E+06		8.20E+03		2.30E+05
				Mean	4.81E+11	2.01E+06	3.60E+05	3.99E+06	1.21E+07	5.80E+04	4.51E+03	2.60E+03	1.41E+05

Operational Performance				Year	Releases to water, Bq						
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)		Pu-239 + Pu-240	Sr-90	Am-241	Am-243	Cm-242	Cm-243	Cm-244
Forsmark NPP 3	1985	1170	3300	2010		3.36E+05		1.46E+05	3.72E+04		2.00E+04
				2011	2.40E+04		1.40E+04	7.40E+04	6.00E+05	1.20E+03	3.00E+05
				2012	7.90E+03		1.40E+04	1.50E+05	1.10E+05	3.30E+02	8.20E+04
				Mean	1.60E+04	3.36E+05	1.40E+04	1.23E+05	2.49E+05	7.65E+02	1.34E+05

Data source for: Radiation Protection Reports 2010, 2011, 2012 (not publicly available therefore provided by Forsmark Radiation Protection Manager and the Swedish Regulator, SSM). IAEA PRIS (last updated 2014)

Table B7: Publicly available discharge data for **Japanese Nuclear Power Plants**, 2010-2012

Nuclear Power Station	Year	Releases to air (Bq)				Releases to water (excluding ^{3}H) (Bq)		Releases to water (tritium discharges only) (Bq)		Radioactive solid waste				
		Noble Gases	ARCTV (Noble Gases)	Iodine (^{131}I)	ARCTV (Iodine)		ARCTV (LRW excl. ^{3}H)		ARCTV (LRW - tritium discharges)	No. Of Drums Generated	No. Of Drums Incinerated / Compacted	No. Of Control Rods	No. Of Channel Boxes	Resin (m^3)
Fukushima II NPP (Daiichi)	2010 [1]	3.60E+12	-	6.20E+11	-	ND	-	1.60E+12	-	2397	1472	-	-	-
	2011 [1]	1.30E+10	-	1.90E+10	-	1.60E+06	-	2.30E+12	-	71	0	-	-	-
	2012	ND	5.50E+15	ND	2.30E+11	ND	1.40E+11	8.00E+11	-	1191	0	0	0	27
Hamaoka NPP [3]	2010	ND	-	7.90E+08	-	ND	-	6.40E+11	-	5284	4464	-	-	-
	2011	ND	-	4.00E+07	-	ND	-	4.60E+11	-	3632	2840	-	-	-
	2012	ND	3.60E+15	ND	1.10E+11	ND	3.70E+10	2.00E+11	-	4908	3756	1	13	7
Kashiwazaki-Kariwa NPP	2010	ND	-	1.60E+07	-	ND	-	6.60E+11	-	3387	40	-	-	-
	2011 [4]	ND	-	8.40E+06	-	ND	-	4.60E+11	-	3141	2066	-	-	-
	2012	ND	6.70E+15	ND [2]	2.30E+11	ND	2.50E+11	2.60E+11	-	4525	3607	27	408	56
Shika NPP	2010	ND	-	ND	-	ND	-	2.80E+11	-	1388	576	-	-	-
	2011	ND	-	ND	-	ND	-	2.10E+11	-	1364	648	-	-	-
	2012	ND	2.30E+15	ND	4.80E+10	ND	7.40E+10	1.10E+10	-	1080	388	12	0	7

Information Sources

IAEA Power Reactor Information System: http://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=JP [Accessed 20.03.14]

JNES, 2013

Notes

ND: Below the limit of detection when measured in accordance with the Guide for Monitoring of Effluent Released from Light Water Nuclear Power Reactor Facilities

ARCTV: Annual release control target value

LRW: Liquid Radioactive Waste

All data reported in the table is publicly available (JNES, 2013)

The publicly available data reports total discharges from all the units at each of the Nuclear Power Stations. It was not possible to locate discharge data for individual units.

Information relating to the date of commencement of commercial operation, reactor size and reator type can be found in the list of BWRs

1: 2011 discharges of noble gases attributed to the accident at the Fukushima Daiichi Nuclear Power Station

2: Monitoring system defect - potential breach of limit stated in NRA guidance (NRA, 2001c)

3: ARCTVs are the total values corresponding to Units 3 to 5

4: 2011 discharges of iodine are presumed attributable to the accident at the Fukushima Daiichi Nuclear Power Station

Table B8: Reported radioactive discharges to air from **United States Nuclear Power Plants**, 2010-2012

Detailed releases to air for US BWRs (2010, 2011, 2012)

Operational Performance				Year of data	Releases to air, Bq [(2)]				
Reactor Name	Year on grid	Net electrical capacity (MWe)	Thermal capacity (MWth)		Noble gases	Total Iodines	Particulates	H-3	C-14
Clinton-1	1987	1065	3473	2010	4.11E+10	7.53E+05	3.10E+06	6.93E+11	5.77E+11
				2011	2.52E+11	9.11E+05	8.02E+06	6.08E+11	5.54E+11
				2012	3.07E+10	2.36E+05	8.07E+04	7.79E+11	5.99E+11
				Mean	1.08E+11	6.33E+05	3.73E+06	6.93E+11	5.77E+11
Grand Gulf-1	1985	1266	4408	2010	1.92E+13	1.06E+08	3.26E+06	8.66E+11	3.52E+11
				2011	1.65E+13	3.96E+06	3.30E+06	1.06E+12	3.52E+11
				2012	1.67E+13	1.55E+07	8.42E+06	7.83E+11	4.18E+11
				Mean	1.75E+13	4.18E+07	4.99E+06	9.03E+11	3.74E+11
LaSalle-1	1984	1137	3546	2010	7.09E+13	1.15E+09	6.79E+08	1.62E+12	6.08E+11
LaSalle-2	1984	1140	3546	2011	8.92E+13	9.65E+08	4.31E+08	1.51E+12	1.26E+12
		2277	7092	2012	1.36E+14	2.29E+09	4.03E+08	4.69E+11	1.26E+12
				Mean	9.88E+13	1.47E+09	5.04E+08	1.20E+12	1.07E+12
Limerick-1	1986	1130	3515	2010	2.00E+12	<LLD[(3)]	1.31E+05	1.58E+12	6.96E+11
Limerick-2	1990	1134	3515	2011	6.92E+12	1.20E+06	1.49E+08	1.69E+12	1.26E+12
		2264	7030	2012	2.65E+12	5.00E+06	2.44E+00	2.65E+12	1.21E+12
				Mean	3.88E+12	2.07E+06	4.96E+07	1.97E+12	1.06E+12

Table B8: Reported radioactive discharges to air from **United States Nuclear Power Plants**, 2010-2012 (table 8 continued)

Operational Performance				Year of data	Releases to air, Bq [2]				
Reactor Name	Year on grid	Net electrical capacity (MWe)	Thermal capacity (MWth)		Noble gases	Total Iodines	Particulates	H-3	C-14
Nine Mile Point-2	1988	1276	3988	2010	1.50E+13	1.84E+08	2.74E+08	3.52E+12	5.82E+11
				2011	1.26E+13	9.94E+07	6.26E+07	2.48E+12	6.23E+11
				2012	3.86E+12	6.69E+07	1.91E+08	2.74E+12	6.02E+11
				Mean	1.05E+13	1.17E+08	1.76E+08	2.82E+12	6.02E+11
Perry-1	1987	1240	3758	2010	9.59E+10	7.85E+06	0.00E+00	3.07E+11	6.33E+11
				2011	6.92E+09	1.54E+06	0.00E+00	9.41E+10	5.53E+11
				2012	3.81E+12	2.21E+06	5.31E+05	1.33E+11	6.89E+11
				Mean	1.30E+12	3.87E+06	1.77E+05	1.78E+11	6.25E+11
Susquehanna-1	1983	1257	3952	2010	9.14E+10	<MDC[4]	6.09E+06	1.15E+12	9.07E+11
Susquehanna-2	1985	1257	3952	2011	<MDC[4]	<MDC[4]	8.57E+06	1.74E+12	8.51E+11
		2514	7904	2012	<MDC[4]	<MDC[4]	3.22E+06	2.57E+11	1.41E+11
				Mean	9.14E+10	<MDC[4]	5.96E+06	1.05E+12	1.05E+12

Data Sources

United States Nuclear Regulatory Commission (USNRC). 2014. Annual Radioactive Effluent Release Reports 2010, 2011 and 2012.Available from: http://www.nrc.gov/reactors/operating/list-power-reactor-units.html. (Accessed March 2014).

IAEA Power Reactor lnformation System. Available from: http://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=US. (Accessed March 2014). JNES, 2013

Notes

(1) For nuclear power plants where there were two units operating on the same site, the operators report the discharge data for the whole site - data is not reported for individual units.

(2) The US nuclear power plants report discharge data as curies Ci. For the purposes of this study, these values have been converted into Becquerel's Bq: 1 Ci= 3.7×10^{10} Bq

(3) <LLD = less than the lower limit of detection. The "less than" value-in units of microcuries per cubic centimetre (pCi/cc) is used when no radioactivity was detected and represents the lower limit of detection (LLD) value for a single sample.

(4) MDC = minimum detectable concentration (used in Susquehanna-1 & -2 data reporting). If a radionuclide was not detected, zero activity was used for that isotope in dose calculations and the activity is listed as "<MDC"(less than the minimum detectable concentration). <MDC indicates that no activity was positively detected in any sample when sampled.

Table B9: Reported radioactive liquid discharges from **United States Nuclear Power Plants**, 2010-2012

Detailed releases to water for US BWRs (2010, 2011, 2012)

Operational Performance				Year of data	Releases to water, Bq [2]		
Reactor Name	Year on grid	Net electrical capacity (MWe)	Thermal capacity (MWth)		Noble gases	H-3	Dissolved and entrained gases
Clinton-1	1987	1065	3473	2010	NR[3]	NR[3]	NR[3]
				2011	NR[3]	NR[3]	NR[3]
				2012	NR[3]	NR[3]	NR[3]
				Mean			
Grand Gulf-1	1985	1266	4408	2010	5.62E+08	2.11E+12	1.25E+08
				2011	9.84E+08	2.18E+12	9.95E+07
				2012	3.10E+09	3.77E+12	1.78E+08
				Mean	1.55E+09	2.69E+12	1.34E+08
LaSalle-1	1984	1137	3546	2010	<LLD [4]	<LLD [4]	<LLD [4]
LaSalle-2	1984	1140	3546	2011	<LLD [4]	<LLD [4]	<LLD [4]
		2277	7092	2012	<LLD [4]	<LLD [4]	<LLD [4]
				Mean			
Limerick-1	1986	1130	3515	2010	9.44E+07	2.89E+11	1.78E+05
Limerick-2	1990	1134	3515	2011	5.40E+07	6.59E+11	3.13E+06
		2264	7030	2012	4.59E+07	6.03E+11	3.21E+06
				Mean	6.48E+07	5.17E+11	2.17E+06

Table B9: Reported radioactive liquid discharges from **United States Nuclear Power Plants**, 2010-2012 (table 9 continued)

Operational Performance				Year of data	Releases to water, Bq [2]		
Reactor Name	Year on grid	Net electrical capacity (MWe)	Thermal capacity (MWth)		Noble gases	H-3	Dissolved and entrained gases
Nine Mile Point-2	1988	1276	3988	2010	1.02E+07	1.78E+11	1.91E+07
				2011	NR [3]	NR [3]	NR [3]
				2012	NR [3]	NR [3]	NR [3]
				Mean	1.02E+07	1.78E+11	1.91E+07
Perry-1	1987	1240	3758	2010	3.55E+08	6.58E+11	LLD
				2011	1.38E+09	1.30E+12	5.99E+03
				2012	1.22E+09	8.56E+11	6.57E+06
				Mean	9.86E+08	9.38E+11	3.29E+06
Susquehanna-1	1983	1257	3952	2010	4.13E+09	2.12E+12	<MDC[5]
Susquehanna-2	1985	1257	3952	2011	8.46E+08	1.92E+12	4.74E+05
		2514	7904	2012	1.34E+08	2.76E+12	3.89E+05
				Mean	1.70E+09	2.27E+12	4.31E+05

Data Sources

United States Nuclear Regulatory Commission (USNRC). 2014. Annual Radioactive Effluent Release Reports 2010, 2011 and 2012. Available from: http://www.nrc.gov/reactors/operating/list-power-reactor-units.html.(Accessed March 2014).

IAEA Power Reactor lnformation System. Available from:http://www.iaea.org/PRIS/CountryStatistics/CountryDetails.aspx?current=US. (Accessed March 2014).JNES, 2013

Notes

(1) For nuclear power plants where there were two units operating on the same site, the operators report the discharge data for the whole site-data is not reported for individual units.

(2) The US nuclear power plants report discharge data as curies Ci. For the purposes of this study, these values have been converted into Becquerel's Bq: 1 Ci =3.7 x 10^{10} Bq

(3) NR =No Release i.e. no releases occurred during this period.

(4) <LLD = less than the lower limit of detection. The “less than” value in units of microcuries per cubic centimetre (pCi/cc) is used when no radioactivity was detected and represents the lower limit of detection (LLD) value for a single sample.

(5) MDC = minimum detectable concentration (used in Susquehanna-1 & -2 data reporting). If a radionuclide was not detected, zero activity was used for that isotope in dose calculations and the activity is listed as "<MDC"(less than the minimum detectable concentration). <MDC indicates that no activity was positively detected in any sample when sampled.

Table B10: Reported radioactive solid waste arisings for **Cofrentes NPP**, 2010-2012

Reactor				Year	Gross electric production (MWh)	Generation of waste (t)					
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)			Non-Hazardous waste (t)	Non-Hazardous waste normalised to electric production (t/MWh)	Hazardous waste (t)	Hazardous waste normalised to electric production (t/MWh)	LLW and ILW (t)	LLW and ILW normalised to electric production (t/MWh)
Cofrentes	1984	1064	3237	2010	9549319	2013.55	2.11E-04	41.36	4.33E-06	174.9	1.83E-05
				2011	7900455	3825.05	4.84E-04	298.312	3.78E-05	212.28	2.69E-05
				2012	9376203	2090.1	2.23E-04	60.113	6.41E-06	161.94	1.73E-05
				Mean	8941992	2.64E+03	3.06E-04	1.33E+02	1.62E-05	1.83E+02	2.08E-05

Appendix C: Non-radioactive discharge data

Table C1: Detailed non-radioactive chemical releases to water for **Cofrentes BWR**, 2010-2012

Operational Performance				Chemical	Monthly releases to water during 2010-2012								
					Jan 2010	Jan 2011	Jan 2012	Feb 2010	Feb 2011	Feb 2012	Mar 2010	Mar 2011	Mar 2012
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)	Free chlorine residual (mg/l)	<0.005	<0.005	<0.005	<0.1	<0.1	<0.005	<0.005	<0.005	<0.005
Cofrentes	1984	1064	3237	pH	8.4	8.5	8.3	8.25	8.45	8.4	8.3	8.6	8.5
				Conductivity at 20°C (µS/cm)	2440	2180	2060	2390	2530	2000	2600	2030	2020
				Thick Solids	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected
				Solids capable of settling (ml/l)	<0.5	<0.5	<0.5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5
				Total Suspended Solids (mg/l)	10	<5	16	6.8	12.6	17	<5	11	11
				DBO (mg/l)	3	4	3	<5	<10	<2	5	3	4
				DQO (mg/l)	13	15	14	<10	<10	12	12	12	14
				Colour (mg/l Pt/Co)	<5	<5	5	<1	<5	10	5	<5	10
				Boron (mg/l)	0.136	0.114	0.114	0.16	0.1	0.113	0.158	0.0966	0.114
				Fluoride (mg F/l)	0.65	0.62	0.48	0.8	0.6	0.41	0.76	0.55	0.35
				Chlorides (mg/l)	2.75	194	201	303.2	207.9	211	327	202	154
				Sulfates (mg/l)	908	839	812	961.9	896	826	1010	770	838
				Sulfites (mg/l)	<0.5	<0.5	<0.5	<0.4	<0.4	<0.5	<0.5	<0.5	<0.5
				Sulfides (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				Cyanide (mg/l)	<0.005	<0.005	<0.005	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005
				Total phosphorous (mg/l)	0.21	0.192	0.26	0.2	0.2	0.246	0.23	0.14	0.172
				Ammonium (mg/l)	0.064	0.08	0.059	<0.1	0.31	0.094	0.087	0.088	0.03
				Ammonia (no ionizable) (mg/l)	<0.010	0.012	<0.01	<0.025	<0.025	<0.01	<0.010	<0.01	<0.01
				Nitric Nitrogen (mg/l)	4.2	3.3	3.87	4.8	4.2	4.69	4.4	4.4	3.19
				Nitrites (mg/l)	<0.1	<0.05	<0.05	0.02	0.023	<0.05	0.082	<0.05	<0.05
				Total Nitrogen (TKN) (mg/l)	<1	1.5	<1	<1	<1	1.05	<1	<1	3
				Oils and fats (mg/l)	<0.5	<0.5	<0.5	0.07	0.05	<0.5	<0.5	<0.5	<0.5
				Anionic surfactants (mg/l)	<0.05	0.071	<0.05	0.11	<0.1	<0.05	0.17	<0.05	<0.05
				Aldehydes (mg/l)	<0.5	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				Aluminum (mg/l)	0.182	0.084	0.164	0.124	0.051	0.192	0.137	0.146	0.199
				Antimony (mg/l)	<0.0001	0.00019	0.0003	<0.003	<0.003	0.00021	<0.0001	0.00014	0.00014
				Arsenic (mg/l)	0.0012	0.0015	0.00127	<0.005	<0.005	0.0012	0.0012	0.0011	0.0011
				Barium (mg/l)	0.079	0.103	0.0808	0.061	0.065	0.0776	0.095	0.0711	0.0825
				Cobalt (mg/l)	<0.001	<0.001	<0.001	<0.01	<0.01	<0.001	<0.001	<0.001	<0.001
				Copper (mg/l)	<0.001	0.0028	0.00201	<0.005	<0.005	0.00267	0.0014	0.00281	0.00158
				Chromium (mg/l)	<0.001	<0.001	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001
				Chromium VI (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
				Tin (mg/l)	<0.001	<0.001	<0.001	<1	<1	<0.001	<0.001	<0.001	<0.001
				Iron (mg/l)	0.028	0.0078	0.00767	0.02	0.013	0.0321	0.02	0.0285	0.0176
				Manganese (mg/l)	<0.001	<0.001	<0.001	<0.005	<0.005	0.00132	0.0015	<0.001	<0.001
				Nickel (mg/l)	0.001	<0.001	<0.001	<0.005	<0.005	<0.001	0.0011	<0.001	<0.001
				Silver (mg/l)	<0.001	<0.001	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001
				Lead (mg/l)	<0.001	<0.001	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001
				Selenium (mg/l)	0.0029	0.0021	0.00307	<0.001	<0.001	0.00235	0.0041	0.0031	0.00297
				Zinc (mg/l)	0.019	0.016	0.0205	0.0017	<0.005	0.0256	0.018	0.0184	<0.005
				Mercury (mg/l)	<0.0001	<0.0001	<0.0001	<0.001	<0.001	<0.0001	<0.0002	<0.0001	<0.0001
				Sodium (mg/l)	141	125	118	185.9	126.8	115	166	104	124
				Calcium (mg/l)	278	350	320	305.86	337.32	311	352	277	
				Cadmium (mg/l)	Non detected	Non detected	<0.0001	Non detected	Non detected	<0.0001	Non detected	Non detected	<0.0001
				Magnesium (mg/l)	92.2	104	96.6	120.2	105.36	94.6	103	81.6	102
				SAR	1.9	1.5	1.5	2.3	1.5	1.5	2	1.4	1.5
				Total phenols (mg/l)	<0.001	<0.001	<0.001	<0.1	<0.1	<0.001	<0.001	<0.001	<0.001
				Hydrocarbons (mg/l)	<0.025	<0.025	<0.025	<0.050	<0.05	<0.025	<0.025	<0.025	<0.025
				Minimum total pestcides (µg/l)	<0.1	<0.1	<0.1	<0.1	<0.01	<0.1	<0.1	<0.1	<0.1

Operational Performance				Chemical	Monthly releases to water during 2010-2012							
					Apr 2010	Apr 2011	Apr 2012	May 2010	May 2011	May 2012	Jun 2010	Jun 2011
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)	Free chlorine residual (mg/l)	<0.10	<0.1	<0.005	<0.005	<0.005	<0.005	<0.10	<0.1
Cofrentes	1984	1064	3237	pH	8.34	8.81	8.6	8.4	8.5	8.7	8.33	8.25
				Conductivity at 20°C (µS/cm)	2710	2160	2090	2520	2180	2300	2420	2220
				Thick Solids	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected
				Solids capable of settling (ml/l)	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1
				Total Suspended Solids (mg/l)	6.8	4.4	2	<5	<5	6	<2	3.5
				DBO (mg/l)	<5	<10	6	5	4	2	6	<10
				DQO (mg/l)	<10	<10	13	26	13	17	28	<10
				Colour (mg/l Pt/Co)	<1	<5	<5	10	5	<5	<1	6.2
				Boron (mg/l)	0.14	<0.1	0.104	0.118	0.16	0.133	0.14	<0.1
				Fluoride (mg F/l)	0.7	0.6	0.49	0.71	0.46	0.57	0.6	0.6
				Chlorides (mg/l)	331.7	219.1	215	253	117	248	238.2	216.7
				Sulfates (mg/l)	1057.8	811.7	827	999	532	958	1014	978.1
				Sulfites (mg/l)	0.5	<0.4	<0.5	<0.5	<0.5	<0.5	<0.4	<0.4
				Sulfides (mg/l)	0.3	<0.1	<0.1	<0.1	<0.1	<0.1	0.3	0.3
				Cyanide (mg/l)	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005	<0.02	<0.02
				Total phosphorous (mg/l)	0.19	0.2	0.192	0.18	0.164	0.205	0.2	0.22
				Ammonium (mg/l)	<0.1	0.136	<0.02	<0.02	0.026	0.105	<0.10	0.088
				Ammonia (no ionizable) (mg/l)	<0.0025	0.01	<0.002	<0.010	<0.01	0.017	<0.025	<0.03
				Nitric Nitrogen (mg/l)	3.9	3.7	3.94	2.7	2.16	4.18	2.9	3.4
				Nitrites (mg/l)	0.039	0.026	0.109	<0.05	0.0685	0.055	0.04	0.038
				Total Nitrogen (TKN) (mg/l)	<1	<2	1.52	<1	<1	1.16	<1	<2
				Oils and fats (mg/l)	<0.05	<0.05	<0.5	<0.5	<0.5	<0.5	0.07	0.21
				Anionic surfactants (mg/l)	<0.1	<0.1	<0.05	<0.05	0.094	<0.05	0.1	<0.1
				Aldehydes (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				Aluminum (mg/l)	0.19	0.067	0.114	0.146	0.092	0.157	<0.05	<0.05
				Antimony (mg/l)	<0.003	<0.003	0.0001	0.00013	0.00012	0.00019	<0.003	<0.003
				Arsenic (mg/l)	<0.005	<0.005	0.0014	0.0012	0.0013	0.0011	<0.005	<0.005
				Barium (mg/l)	0.075	0.023	0.0663	0.104	0.0777	0.105	0.055	0.021
				Cobalt (mg/l)	<0.010	<0.001	<0.001	<0.001	<0.001	<0.001	<0.010	<0.01
				Copper (mg/l)	<0.005	<0.005	<0.001	0.0083	0.0018	0.00635	<0.005	<0.01
				Chromium (mg/l)	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005
				Chromium VI (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
				Tin (mg/l)	<1	<1	<0.001	<0.001	<0.001	<0.001	<1	<1
				Iron (mg/l)	0.143	0.033	0.00812	0.014	0.0132	0.0149	<0.010	<0.01
				Manganese (mg/l)	<0.005	<0.005	<0.001	<0.001	<0.001	0.00132	<0.005	0.005
				Nickel (mg/l)	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005
				Silver (mg/l)	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005
				Lead (mg/l)	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005
				Selenium (mg/l)	<0.001	<0.001	0.00309	0.0016	0.0025	0.0028	0.001	<0.001
				Zinc (mg/l)	<0.005	0.007	0.0161	0.0089	0.011	0.0246	<0.005	<0.005
				Mercury (mg/l)	<0.001	<0.001	<0.0001	<0.1	0.000048	<0.0001	<0.001	<0.001
				Sodium (mg/l)	195.1	126.4	116	179	98.7	167	110	126.8
				Calcium (mg/l)	324.66	285.15		384	280		370.51	322.6
				Cadmium (mg/l)	Non detected	Non detected	<0.00008	Non detected	Non detected	<0.00008	Non detected	Non detected
				Magnesium (mg/l)	121.11	98.72	92.2	129	83.7	137	116.9	106.8
				SAR	2.3	2	1.4	2	1.3	1.9	1.3	2
				Total phenols (mg/l)	<0.10	<0.1	<0.001	<0.001	<0.001	<0.001	<0.10	<0.1
				Hydrocarbons (mg/l)	<0.050	<0.05	<0.025	<0.025	<0.025	<0.025	<0.050	<0.05
				Minimum total pestcides (µg/l)	<0.01	<0.01	<0.1	<0.1	<0.1	<0.1	<0.01	<0.01

Operational Performance				Chemical	Monthly releases to water during 2010-2012								
					Jun 2012	Jul 2010	Jul 2011	Jul 2012	Aug 2010	Aug 2011	Aug 2012	Sep 2010	Sep 2011
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)	Free chlorine residual (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.10	<0.1	<0.005	<0.005	<0.005
Cofrentes	1984	1064	3237	pH	8.5	8.6	8.6	8.8	8.52	8.55	8.6	8.4	8.5
				Conductivity at 20°C (µS/cm)	2620	2410	2380	2580	2470	2330	2490	2390	2070
				Thick Solids	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected
				Solids capable of settling (ml/l)	<0.5	<0.5	<0.5	<0.5	<0.1	<0.1	<0.5	<0.5	<0.5
				Total Suspended Solids (mg/l)	7	14	10	9	3.2	4.8	4	7	11
				DBO (mg/l)	4	3	<2	4	<5	4	5	<2	<2
				DQO (mg/l)	12	11	10	15	12	14	16	13	17
				Colour (mg/l Pt/Co)	10	5	5	5	<1.0	11.7	<5	<5	15
				Boron (mg/l)	0.134	0.169	0.126	0.13	0.14	0.15	0.129	0.12	0.139
				Fluoride (mg F/l)	0.94	0.54	0.97	0.66	0.7	0.6	0.71	0.64	0.58
				Chlorides (mg/l)	234	144	247	199	244.2	217.8	202	245	194
				Sulfates (mg/l)	1000	995	917	843	1006.7	968.6	1060	988	834
				Sulfites (mg/l)	<0.5	<0.5	<0.5	<0.5	<0.4	<0.4	<0.5	<0.5	<0.5
				Sulfides (mg/l)	<0.1	0.1	<0.1	<0.1	0.2	<0.1	<0.1	<0.1	<0.1
				Cyanide (mg/l)	<0.005	<0.005	<0.005	<0.005	0.02	<0.02	<0.005	<0.005	<0.005
				Total phosphorous (mg/l)	0.221	0.25	0.2	0.177	0.24	0.37	0.182	0.22	0.209
				Ammonium (mg/l)	0.116	0.081	0.11	0.089	<0.10	<0.05	0.123	0.044	0.032
				Ammonia (no ionizable) (mg/l)	0.016	<0.010	0.012	0.017	<0.025	<0.03	0.016	<0.010	<0.01
				Nitric Nitrogen (mg/l)	2.96	1.7	3.22	2.56	2.9	2.4	2.45	2.8	2.3
				Nitrites (mg/l)	<0.05	0.054	<0.05	0.067	0.043	0.042	<0.05	<0.05	0.129
				Total Nitrogen (TKN) (mg/l)	1.17	<1	<1	1.13	<1	<2	1.07	<1	<1
				Oils and fats (mg/l)	<0.5	<0.5	<0.5	<0.5	0.24	<0.05	<0.5	<0.5	<0.5
				Anionic surfactants (mg/l)	<0.05	<0.05	<0.05	<0.05	<0.1	0.12	<0.05	0.14	0.136
				Aldehydes (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				Aluminum (mg/l)	0.0902	0.132	0.0672	0.124	0.056	0.123	0.0712	0.121	0.173
				Antimony (mg/l)	0.00026	0.00018	0.00018	0.00021	<0.003	<0.003	0.00022	0.00018	0.00019
				Arsenic (mg/l)	0.0019	0.002	0.0019	0.0022	<0.005	<0.005	0.0019	0.0021	0.0023
				Barium (mg/l)	0.102	0.114	0.104	0.0936	0.082	0.075	0.0919	0.112	0.0862
				Cobalt (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.010	<0.01	<0.001	<0.001	<0.001
				Copper (mg/l)	0.00285	0.0023	0.0023	0.00364	<0.005	<0.01	0.00151	0.00148	0.00256
				Chromium (mg/l)	0.00306	<0.001	<0.001	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001
				Chromium VI (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
				Tin (mg/l)	<0.001	<0.001	<0.001	<0.001	<1	<1	<0.001	<0.001	<0.001
				Iron (mg/l)	0.0225	0.0432	0.0281	0.0294	0.013	0.021	0.0117	0.0254	0.015
				Manganese (mg/l)	0.00115	0.0017	0.0037	0.00102	<0.005	<0.005	<0.001	<0.001	<0.001
				Nickel (mg/l)	<0.001	0.0032	0.001	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001
				Silver (mg/l)	<0.001	<0.001	0.001	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001
				Lead (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001
				Selenium (mg/l)	0.00324	0.0035	0.0025	0.00301	<0.001	<0.001	0.00254	0.0026	0.00293
				Zinc (mg/l)	0.0153	0.0207	0.0242	0.0136	<0.005	<0.005	0.0144	0.0172	0.0158
				Mercury (mg/l)	<0.0001	<0.0001	0.000022	<0.0001	<0.001	<0.001	<0.0001	<0.0001	<0.00002
				Sodium (mg/l)	138	146	140	128	143.8	132.2	120	142	116
				Calcium (mg/l)		356	395		302.52	344.6		372	319
				Cadmium (mg/l)	<0.00008	Non detected	Non detected	<0.00008	Non detected	Non detected	<0.00008	Non detected	Non detected
				Magnesium (mg/l)	121	110	115	116	106	112.25	108	107	103
				SAR	1.6	1.7	1.6	1.5	1.8	2	1.4	1.7	1.4
				Total phenols (mg/l)	<0.001	<0.001	<0.001	<0.001	<0.10	<0.1	<0.001	<0.001	<0.001
				Hydrocarbons (mg/l)	<0.025	<0.025	<0.025	<0.025	<0.050	<0.05	<0.025	<0.025	<0.025
				Minimum total pestcides (µg/l)	<0.1	<0.1	<0.1	<0.1	<0.01	<0.01	<0.1	<0.1	<0.1

Operational Performance				Chemical	Monthly releases to water during 2010-2012						
					Sep 2012	Oct 2010	Oct 2011	Oct 2012	Nov 2010	Nov 2011	Nov 2012
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)	Free chlorine residual (mg/l)	<0.005	<0.10	<0.1	<0.005	<0.005	<0.005	<0.005
Cofrentes	1984	1064	3237	pH	8.6	8.56	8.4	8.7	8.4	7.6	8.4
				Conductivity at 20°C (µS/cm)	2500	2470	1030	2540	2260	1280	2300
				Thick Solids	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected	Non detected
				Solids capable of settling (ml/l)	<0.5	<0.1	<0.1	<0.5	<0.5	<0.5	<0.5
				Total Suspended Solids (mg/l)	7	10.2	5.7	10	9	10	6
				DBO (mg/l)	2	5	<4	2	<2	5	3
				DQO (mg/l)	14	13	<10	15	13	12	10
				Colour (mg/l Pt/Co)	<5	<1	19.2	5	<5	5	5.9
				Boron (mg/l)	0.121	0.15	<0.1	0.153	0.138	0.103	0.139
				Fluoride (mg F/l)	0.46	0.6	0.2	0.57	0.56	0.39	0.76
				Chlorides (mg/l)	203	217	94.3	219	220	139	246
				Sulfates (mg/l)	948	943.7	325.9	924	881	697	917
				Sulfites (mg/l)	<0.5	<0.4	<0.4	<0.5	<0.5	<0.5	<0.5
				Sulfides (mg/l)	<0.1	0.1	0.4	<0.1	<0.1	<0.1	<0.1
				Cyanide (mg/l)	<0.005	<0.02	<0.02	<0.005	<0.005	<0.005	<0.005
				Total phosphorous (mg/l)	0.201	0.27	0.6	0.16	0.19	0.192	0.152
				Ammonium (mg/l)	0.055	<0.10	0.37	0.128	0.044	0.126	0.069
				Ammonia (no ionizable) (mg/l)	0.007	<0.02	<0.025	0.02	<0.010	<0.01	0.006
				Nitric Nitrogen (mg/l)	2.54	2.7	1.1	2.9	2.9	2.37	3.58
				Nitrites (mg/l)	<0.05	0.022	0.019	<0.05	0.13	0.079	<0.05
				Total Nitrogen (TKN) (mg/l)	<1	<1	<2	<1	<1	1.17	<1
				Oils and fats (mg/l)	<0.5	<0.05	0.24	<0.5	<0.5	<0.5	<0.5
				Anionic surfactants (mg/l)	<0.05	<0.1	<0.1	<0.05	<0.05	<0.05	<0.05
				Aldehydes (mg/l)	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1	<0.1
				Aluminum (mg/l)	0.0853	<0.05	0.061	0.0538	0.106	0.154	0.056
				Antimony (mg/l)	0.00022	<0.003	<0.003	0.00031	0.0002	0.00041	0.00021
				Arsenic (mg/l)	0.002	<0.005	<0.005	0.0024	0.0021	0.0021	0.0018
				Barium (mg/l)	0.0801	0.08	0.028	0.089	0.091	0.0603	0.0695
				Cobalt (mg/l)	<0.001	<0.010	<0.01	<0.001	<0.001	<0.001	<0.001
				Copper (mg/l)	<0.001	<0.005	<0.01	<0.001	0.0015	0.0012	0.00106
				Chromium (mg/l)	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001
				Chromium VI (mg/l)	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005	<0.005
				Tin (mg/l)	<0.001	<1	<1	<0.001	<0.001	<0.001	<0.001
				Iron (mg/l)	0.0122	0.013	<0.01	0.0091	0.0141	0.0163	0.00811
				Manganese (mg/l)	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001
				Nickel (mg/l)	<0.001	<0.005	<0.005	<0.001	0.0013	<0.001	<0.001
				Silver (mg/l)	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001
				Lead (mg/l)	<0.001	<0.005	<0.005	<0.001	<0.001	<0.001	<0.001
				Selenium (mg/l)	0.00279	<0.001	<0.001	0.00285	0.0031	0.00284	0.00269
				Zinc (mg/l)	0.0196	0.008	0.006	0.0136	0.0186	0.0142	0.0261
				Mercury (mg/l)	<0.0001	<0.001	<0.001	<0.0001	<0.0001	<0.00002	<0.0001
				Sodium (mg/l)	129	140.8	73.6	138	141	97.3	132
				Calcium (mg/l)		273.51	115.1		361	254	
				Cadmium (mg/l)	<0.00008	Non detected	Non detected	<0.00008	Non detected	Non detected	<0.00008
				Magnesium (mg/l)	115	96.22	43.55	120	<0.001	79.2	111
				SAR	1.5	1.8	1	1.6	1.7	1.4	1.6
				Total phenols (mg/l)	<0.001	<0.10	<0.1	<0.001	<0.001	<0.001	<0.001
				Hydrocarbons (mg/l)	<0.025	<0.05	<0.05	<0.025	<0.025	<0.0025	<0.025
				Minimum total pestcides (µg/l)	<0.1	<0.01	<0.1	<0.1	<0.1	<0.1	<0.1

Operational Performance				Chemical	Monthly releases to water during 2010-2012			
					Dec 2010	Dec 2011	Dec 2012	Limit per month
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)	Free chlorine residual (mg/l)	<0.10	<0.005	<0.005	0.005
Cofrentes	1984	1064	3237	pH	8.46	8.4	8.8	5.5-9.5
				Conductivity at 20°C (µS/cm)	2990	2070	2530	n/a
				Thick Solids	Non detected	Non detected	Non detected	Non detected
				Solids capable of settling (ml/l)	<0.1	<0.5	<0.5	<0.5
				Total Suspended Solids (mg/l)	12.6	22	10	25
				DBO (mg/l)	<10	3	2	6
				DQO (mg/l)	18	17	12	30
				Colour (mg/l Pt/Co)	<5	15	8.2	<20
				Boron (mg/l)	0.12	0.105	0.141	0.7
				Fluoride (mg F/l)	0.6	0.59	0.57	1.7
				Chlorides (mg/l)	211.9	219	200	250
				Sulfates (mg/l)	917.2	836	788	1300
				Sulfites (mg/l)	<0.4	<0.5	<0.5	0.5
				Sulfides (mg/l)	<0.1	<0.1	<0.1	0.5
				Cyanide (mg/l)	<0.02	<0.005	<0.005	0.04
				Total phosphorous (mg/l)	0.32	0.273	0.134	0.5
				Ammonium (mg/l)	<0.05	0.148	0.06	1
				Ammonia (no ionizable) (mg/l)	<0.02	0.01	0.011	0.025
				Nitric Nitrogen (mg/l)	3.9	3.66	3.26	5
				Nitrites (mg/l)	<0.010	<0.05	<0.05	0.15
				Total Nitrogen (TKN) (mg/l)	1.2	1.2	<1	10
				Oils and fats (mg/l)	<0.05	<0.5	<0.5	1
				Anionic surfactants (mg/l)	0.17	<0.05	<0.05	0.2
				Aldehydes (mg/l)	<0.1	<0.1	<0.1	0.1
				Aluminum (mg/l)	0.058	0.163	0.096	0.2
				Antimony (mg/l)	<0.003	<0.0001	0.00032	0.03
				Arsenic (mg/l)	<0.005	0.0014	0.0026	0.05
				Barium (mg/l)	0.07	0.0761	0.0851	1
				Cobalt (mg/l)	<0.010	<0.001	<0.001	0.05
				Copper (mg/l)	<0.005	0.00225	<0.001	0.05
				Chromium (mg/l)	<0.005	<0.001	<0.001	0.05
				Chromium VI (mg/l)	<0.005	<0.005	<0.005	0.005
				Tin (mg/l)	<1	<0.001	<0.001	1
				Iron (mg/l)	<0.010	0.00719	0.00881	1
				Manganese (mg/l)	<0.005	<0.001	<0.001	0.2
				Nickel (mg/l)	<0.005	<0.001	<0.001	0.05
				Silver (mg/l)	<0.005	<0.001	<0.001	0.05
				Lead (mg/l)	<0.005	<0.001	<0.001	0.05
				Selenium (mg/l)	<0.001	0.00296	0.00301	0.001
				Zinc (mg/l)	0.012	0.0203	0.0204	0.03
				Mercury (mg/l)	<0.001	0.00012	<0.0001	n/a
				Sodium (mg/l)	130.9	166	139	n/a
				Calcium (mg/l)	292.73	415		n/a
				Cadmium (mg/l)	Non detected	Non detected	<0.00008	
				Magnesium (mg/l)	97.6	137	116	n/a
				SAR	1.7	1.8	1.6	9
				Total phenols (mg/l)	<0.10	<0.001	<0.001	0.001
				Hydrocarbons (mg/l)	<0.050	<0.025	<0.025	0.025
				Minimum total pestcides (µg/l)	<0.01	<0.1	<0.1	0.3

Data source: Cofrentes Environmental Statements 2010-2012. Publicly available data which can be found at: http://www.cncofrentes.es/wcofrnts/corporativa/iberdrola?IDPAG=ENCOFMEDINF&codCache=13952584633933000.

Table C2: Consumption of the most frequently used chemicals within **Cofrentes NPP**, 2010-2012

Operational Performance				Year	Gross electric production (MWh)	Consumption (t)				Consumption relative to power rating (t/MWh)			
Reactor Name	Year on grid	Net Electrical Capacity, (Mwe)	Thermal Capacity (MWth)			Sulphuric acid	Sodium hydroxide	Sodium hypochloride	Poly aluminium chloride	Sulphuric acid	Sodium hydroxide	Sodium hypochloride	Poly aluminium chloride
Cofrentes	1984	1064	3237	2010	9549319	3438.55	48.3	352.84	185.09	3.60E-06	5.06E-06	3.69E-05	1.94E-05
				2011	7900455	2798.4	47.74	350.32	174.75	3.54E-04	6.04E-06	4.43E-05	2.21E-05
				2012	9376203	2675.2	32.05	317.48	63.42	2.85E-04	3.42E-06	3.39E-05	6.76E-06
				Mean	8941992	2.97E+03	4.27E+01	3.40E+02	1.41E+02	2.14E-04	4.84E-06	3.84E-05	1.61E-05

Data source: Cofrentes Environmental Statements 2010-2012. Publicly available data which can be found at: http://www.cncofrentes.es/wcofrnts/corporativa/iberdrola?IDPAG=ENCOFMEDINF&codCache=13952584633933000.

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