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01	Second issue - update of sections 2, 3, 4 and 5 including addition of monthly discharge estimates and annual maximum discharges	26-11-08
02	PCSR June 2009 update: - Inclusion of references; - Consistency achieved with December 2008 design freeze; - Clarification of text Update equivalent PCER chapter	19-09-09
03	PCER March 2010 update - Relevant references marked as CCI - Complementary information included in sections 1, 2, 3.1, 3.2.2, 3.2.3, 3.2.6, 6.2.1.3.1, 6.3.1.3, 6.4.1.2.1, 6.4.2.1, 7.3.1.3, 7.4.1, 7.4.4.2.1 and 8.1.1 - Minor editorial changes	28-03-10
04	PCER March 2011 update • Minor editorial changes • Update and addition of references (§3.1, §3.2.2, §3.2.3) • §3.2.1, "C1 and C4 containers are classified as IP2 packages" added • §6.2.1.3.3, updated to reflect use of enriched boron (37% B-10), consistent with Sub-chapter 5.5	29-03-11
	Protect Commercial marking removed	
05	Consolidated PCER update: - Minor formatting changes - References listed under each numbered section or sub-section heading numbered [Ref-1], [Ref-2], [Ref-3], etc - Minor editorial and typographical changes for clarification / consistency	23-08-2012

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REVISION HISTORY (Cont'd)

Issue	Description	Date
05 (cont'd)	Consolidated PCER update (cont'd): - Statement that no use of MOX is claimed for GDA added (§2) - Updates to reactor chemistry aspects and cross-references to Sub-chapter 5.5 added for consistency (§6.3.1, §6.3.1.3, §6.4.1.1, §6.4.2.1, §8.1.3 (new), §8.1.4, §8.1.5, §8.1.6) - Clarification and minor error corrections (§6.3.1.3, §6.3.2.1, §6.4, §6.4.1.1, §6.4.2.2.1, §6.4.2.3, §7.2.2.1, §7.2.4, §7.4.1, §7.5) - Missing figures reinstated (Appendices A-44 and A-46) - Updates to references (§3.2, §7.4, §8.1, §8.2)	23-08-2012

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SUB-CHAPTER 6.3 - OUTPUTS FOR THE OPERATING INSTALLATION

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This sub-chapter deals with requirements 2.2, 2.3, 2.4, 2.5 and 3.2 of the EA P&I Document [Ref-1].

1. INTRODUCTION

This sub-chapter deals with the estimation of the effluents discharged and the waste produced by the operation of the EPR reactor. The estimates cover:

- spent fuel arisings;
- solid waste arisings (excluding fuel);
- liquid radioactive effluent discharges;
- gaseous radioactive effluent discharges;
- chemical effluent discharges, whether associated with liquid radioactive effluent (lithium hydroxide and boron) or arising from operation of non-nuclear parts of the plant (conditioning amines and phosphate).

This sub-chapter presents the maximum annual discharges.

This sub-chapter details the flow over 24 hours for chemical discharges associated with radioactive effluent (see section 8.1.6), in order to assess short term impacts.

In addition, requirement 2.2 of the Environment Agency Process and Information Document (P&I document, [Ref-1]) requires that design basis estimates for monthly discharges of gaseous and liquid radioactive waste for each radionuclide identified in EU Commission Recommendation 2004/2/Euratom [Ref-2] is provided for the assessment of the generic design of the EPR. In addition to the provision of annual limits, requirement 2.3 of the above document states that "where the requesting party feels it relevant, they may additionally propose limits to reflect an operating cycle, i.e. campaign limits".

The "BAT Demonstration" document [Ref-3] details the solutions implemented for the minimisation at source of waste and the management and abatement of discharges.

2. SPENT NUCLEAR FUEL

This section deals in part with the requirement 2.5 of the EA P&I Document.

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

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

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

As regards its core design and use of fuel, the EPR is an evolved reactor with a design that has benefited from experience gained with existing reactors. It uses the same types of fuel, enriched uranium and plutonium, as existing reactors but design features and enhancements in fuel performance mean that the yield is better.

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

- better overall use of the fuel material as a result of increased operating and safety margins and more efficient use of the neutrons produced. Hence, it follows that there is less use of nuclear material to produce the same amount of energy. It is thus possible to reduce both the consumption of natural uranium and the quantity of waste produced by irradiation, for the same amount of energy provided;

- increased burn-up and increased flexibility to implement various types of MOX or innovative fuel.

The actual fuel management regime that will be applied on the UK EPR is operator dependent. The possibility of different kinds of fuel management has been left open to allow for flexibility of future EPR operations. Benchmark management regimes envisaged are based on a UO_2 core with a cycle of 12, 18 or 22 months or on a 30% MOX core with an 18-month cycle. Operating experience feedback from French plants operating with and without MOX shows that MOX has no significant impact on releases. Maximum releases presented in the GDA submission are consistent with these management regimes and should also be applicable to a plant operated with MOX fuel.

It should be noted that no use of MOX is claimed for GDA; technical capability is described in the safety case for information only.

Improved fuel performance

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

For the EPR, management options considered in the design phase correspond to the optimum of what can be envisaged today using current fuel products; i.e. a maximum burn-up in discharged assemblies of 65 GWd/tU. This can be compared to the maximum burn-up of 52 GWd/tU currently achieved in France.

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

EPR design features

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

- adoption of a **"large core",** comprised of 241 fuel assemblies, compared to the 205 elements of the N4 units, for comparable electrical output. The gains achieved have the following physical bases:

    - reduction in neutron leakage due to the increased size of the core;

- additional assemblies leading to a 9% reduction in the linear power density of the core at nominal power. This enables neutron poisoning due to xenon to be reduced, and above all, a smaller fraction of the core to be refuelled, for a given burn-up and operating cycle length.

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

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

- the use of a solid steel reflector called the "**heavy reflector**". The reduction in the radial neutron leakage it generates, once again, leads to savings of 2 to 3% of natural uranium consumed for a given energy output;

- the improvement in the **overall thermal efficiency**, and in particular the enhanced turbine efficiency, contributes 5% to the reduction in the consumption of uranium.

The gain in overall fuel efficiency (natural uranium) in the EPR compared to N4 units, in view of the expected fuel characteristics in the medium-term, thus reaches 22% for an equivalent energy generation.

For a given quantity of energy produced, the proportional reduction in the quantities of irradiated assemblies produced, as a result of the improvement in fuel use, enables the overall quantities of irradiated materials in the reactor to be reduced.

Similarly, a reduction in the residual quantity of plutonium produced inside the fuel assemblies in the reactor during the cycle should be noted. This arises from better use (-15%) of Plutonium by burn-up in the cycle, which contributes 40% to the overall energy produced.

Hence, the neutronic design, combined with the improvement in its output is a strong feature of the EPR reactor. There is more efficient use of natural uranium resources, better use of irradiated fuel in the reactor, a significant reduction in the long lived radioactive waste produced by the fuel and its cladding, and better in situ use of Plutonium.

More information about the quantities of spent fuel over the station lifetime, spent fuel characteristics are provided in the Solid Radioactive Waste Strategy Report (SRWSR) [Ref-1]. Further information on fuel composition and geometric characteristics are found in Sub-chapter 4.4 of the PCSR.

3. SOLID RADIOACTIVE WASTE

This section deals with requirement 2.4 of the EA P&I Document. As mentioned in Sub-chapter 6.2, different options for treatment, conditioning and packaging processes are presented in the submission reflecting the practices of different utilities. Therefore, after a presentation of the annual estimated production of raw waste, the section deals with characteristics of packaged waste for the EPR reference case (based on French practices) and with characteristics of packaged waste reflecting the practices of other utilities.

3.1. EPR ANNUAL ESTIMATED PRODUCTION OF RAW WASTE

Table 1 below provides, by volume, the annual estimated production of raw waste (prior to conditioning) for each type of waste for one EPR unit. Following a first estimate, based on the feedback from French and German units, a second estimate has been made assuming a significant reduction in the volume of operational waste produced [Ref-1]. In this case the estimated volume of solid waste was determined by combining the best quartile for each type of waste (and not per site), which gives a volume of the order of 80 m^3/year (compared to the 120 m^3 which would result from adding the averages of the 1st quartile of 2004 total volumes for the existing French 1300 MW(e) units). This approach predicts a significant reduction in the volume of operational waste (i.e. VLLW, LLW and ILW) to be produced.

These estimates have been calculated using the EDF tracking system that was implemented and deployed in 1992. The EDF tracking system allows collection and control of all characteristics of waste packages produced by the NPPs (including those undergoing decommissioning) and ensures the total traceability of packages from their collection to final disposal.

Studies show that, for the majority of the streams, the rate of arisings is independent of plant age. Furthermore, there is no evidence of a trend to produce larger quantities of higher activity streams as the plant ages.

Only the raw pre-compacted and non-compactable dry active waste (DAW) production is affected by an apparent variation in the rate of arising as a function of the age of the reactors, in all likelihood as a result of maintenance programmes and major outages. Much of this waste would be suitable for incineration (with an associated volume reduction by a factor of 10); this would result in a much smaller increase in packaged waste volume [Ref-2].

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

- designation at the design stage of clean-waste zoning, enabling better sorting of waste at source and the segregation of conventional waste from non-contaminating work in the restricted area;
- better control of the source term through careful selection of materials in contact with the primary coolant which then leads to a reduction in the production of corrosion products (a reduction in cobalt 60 activity in particular see Sub-chapter 5.5 of the PCSR);
- optimisation of the chemical treatment of primary coolant (see Sub-chapter 5.5 of the PCSR), in particular by:
    - maintaining a constant pH value in the primary coolant by optimised regulation of the lithium concentration;
    - controlling the concentration of dissolved hydrogen in the primary coolant so as to reduce the oxygen content and limit radiolysis;
    - better elimination of the dissolved oxygen during boron recycling, by evaporation and degassing, and recombination of the hydrogen in the gaseous effluent treatment system;

- the potential injection of zinc into the primary system to prevent the incorporation of cobalt in the oxides from zones outside the flux. An analysis has been made of the relative benefits and disadvantages of zinc injection into the primary circuit, and overall it is judged beneficial for the UK EPR (see Sub-chapter 5.5 of the PCSR);

- taking more credit for the selectivity of RPE [NVDS] drainage streams;

- a greater surface area on the RCV [CVCS] purification filters than on the 1300 MW(e) and N4 units, through use of multi-cartridge baskets and not single cartridge.

It should be noted that the volume of solid waste depends on the balance between environmental discharges and packaged waste generation in managing the installation and may therefore change according to the various effluent treatment methods. The target below, for example, does not incorporate the impact in terms of concentrates from any partial treatment of the process drains on the 8TEU [LWPS] evaporator which could be of the order of a few m^3.

	Type of waste	Estimated gross annual volume (m^3)
Process waste	Ion-exchange resins from the nuclear island	3
	Low activity APG [SGBS] ion-exchange resins (without regeneration)	7.5
	Wet sludge (sumps, tanks)	1
	Water filters from effluent treatment	5
	Evaporator concentrates	3
	Air and water filters	4
Operational waste	Pre-compacted operational waste (apparent density. 0.5) and non compactable: maintenance (excluding metals), rubble, decontamination operations, insulation	50
	Oils (and solvents)	2
	Metal waste from maintenance (Scraps)	6
	Operational waste	1
TOTAL		**82.5**

Table 1: Estimated volumes of raw solid waste produced during operation of the UK EPR unit [Ref-1].

3.2. CHARACTERISTICS OF PACKAGED SOLID WASTE FOR THE UK EPR REFERENCE CASE

The reference case treatment and conditioning processes for solid waste are the result of French operating experience (58 PWR units currently in operation – 34 at 900 MW(e), 20 at 1300 MW(e) and 4 at 1500 MW(e)).

The proposed UK EPR strategy is standardised as closely as possible with the Flamanville 3 NPP scheme, including the packaging used (concrete containers, metallic and plastic drums, metallic boxes), whilst recognising the UK specific waste classifications and disposal routes.

Table 2 presents the different waste pathways in the UK taking into account the UK classification for waste and spent fuel.

Halflive / Activity	Short and long lived nuclides
Very Low Level activity (VLLW) (0,1 m3 < 400 kBqβγ or single item < 40 kBq)	Near surface disposal — Landfill sites
Low level activity (LLW) (< 12 GBq/teβγ and < 4 GBq/teα)	Dedicated near surface disposal — LLW repository
Intermediate level activity (ILW)	Pathways under consideration — Interim storage on sites
Spent fuel	

Table 2: Correspondence between waste classification and disposal routes

In addition to the wish to standardise approaches, the scheme is underpinned by mature BAT considerations and complies with the existing French framework of regulations (particularly the disposal specifications of ANDRA), see Chapter 8 of the PCER.

The Solid Waste Treatment System (TES [SWTS], [Ref-1] to [Ref-8]) is described in Sub-chapter 6.4.

Solid waste from the nuclear island and the Effluent Treatment Building that results from normal operation is sent to the TES [SWTS], and is then conditioned for sending to interim storage, off-site to a final storage location or to a treatment plant for additional processing (e.g. incineration or melting).

The solid waste includes:

- spent resins from the demineralisers for the various nuclear systems;
- filters from the various nuclear systems;
- concentrates from the evaporators in the Spent Effluent Treatment System (8TEU [LWPS]);
- high-concentration chemical effluents from decontamination operations;

- sundry operational waste that could be contaminated (such as vinyl, paper or scrap metals).

The treatments, conditioning and packaging are presented in Table 3. The scheme is essentially characterised by the use of incineration for approximately half of the raw waste volume (see PCER Sub-Chapter 6.2 section 3.4.1.2).

	Type of waste	Treatments	Packaging on NPP before shipment
Process waste	Ion-exchange resins from the nuclear island	Embedding	Concrete block 2 m^3
	SGBS ion-exchange resins (without regeneration)	Incineration	Plastic drums 0.2 m^3
	Wet sludge (sumps, tanks)	Cementation	Concrete block 2 m^3
		Cementation	Metallic drums 0.2 m^3
	Water filters from effluent treatment	Cementation	Concrete block 2 m^3
		Cementation	Concrete block 1.23 m^3
		Cementation	Metallic drums 0.2 m^3
	Evaporator concentrates	Incineration	Tank on truck 5 m^3
	Non compactable: air and water filters (85%/15%)	Dismantling, shredding	Metallic drums 0.2 m^3
Operational waste	Pre-compacted operational waste (plastics, clothes, small items…)	Pre compaction on site	Metallic drums 0.2 m^3
		Incineration	Plastic drums 0.2 m^3
	Oils	Incineration	Tank on truck 5 m^3
	Scraps	Melting	Metallic boxes 1 m^3
	Operational waste	Cementation	Concrete block 2 m^3
		Incineration	Metallic drums 0.2 m^3

Table 3: Operational waste arisings, their treatment, conditioning and packaging

3.2.1. Packaging

C1 and C4 - Concrete containers

The referenced packages for ILW are concrete containers of two sizes:

- C1 - concrete container with an external volume of 2 m^3 (ϕ: 1.4m, h: 1.3m). The volume of raw waste is in the range of 310 to 440 litres;
- C4 - concrete container with an external volume of 1.23m^3 (ϕ: 1.1m, h: 1.3 m). The volume of raw waste is kept at 250 litres.

These two packages, due to the properties of their 15 cm concrete thickness, have been qualified, according to ANDRA technical specifications, to have the physical capability to last and confine radioactivity for more than 300 years. They have successfully passed drop tests from 1.2 m.

C1 and C4 containers are classified as IP2 packages.

Figure 1: View of a 1.23 m^3 concrete container

Figure 2: Section of a 1.23 m^3 concrete container with a RCV [CVCS] cartridge inside

Figure 3: Operator finishing the cap

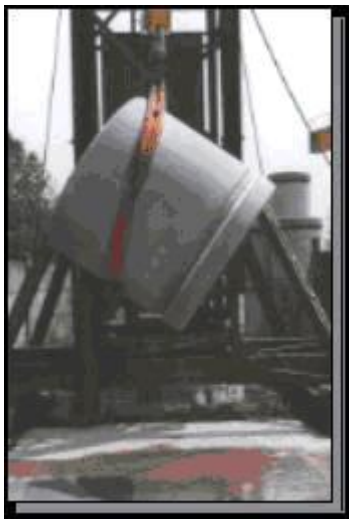

Figure 4: View of a drop test (1.2 m)

Metallic Drum 200 litres

These drums are mainly used for the conditioning of LLW to be shipped directly to the LLW repository.

Waste is pre-compacted inside them on the NPP site (25 tonne) with a resultant increase in waste density from 0.2 to 0.4. These metallic drums can themselves be high pressure compacted in a facility in the vicinity of the repository site.

Drums “pancakes” can be containerised with a mortar into 450 litre metallic drums (final packages).

Figure 5: Metallic drums 200 litres

Plastic Drum 200 litres

These drums made of polypropylene with a cap of high density polyethylene, have been developed specifically for the incineration process. They are directly introduced in the furnace.

Waste is slightly pre-compacted inside the drums on the NPP site with a resultant density increase from 0.2 to 0.25 - 0.3.

Figure 6: Plastic drums 200 litres

Heavy metallic drums 450 litres

This type of drum can be used in the incineration process to collect ashes and clinkers. These are containerised inside by mixing with cement. The thickness of the drum has been increased to minimise contact dose rates.

Metallic Boxes 1 m^3

Metallic waste and cut scraps to be sent for melting are collected and shipped in 1 m^3 metal boxes. This waste is tipped out into the smelter and the boxes are sent back to the site.

Ingots 200 litres

Ingots are produced by the melting process. They are disposed of in the LLW repository. Nevertheless some of them (< 10 Bq/g) could be disposed of as VLLW.

3.2.2. Quantification and radioactive characterisation of EPR waste streams

The EPR annual production of waste (Table 1) and the processing scheme (Table 3) have been further complemented by an analysis of data from about 50,000 waste packages, produced in 2005, 2006 and 2007 by the 1300 MW(e) reactors (20 considered) and the 1500 MW(e) reactors (4 considered) i.e. an analysis including:

- 41,550 drums (metallic and plastic);
- 2,775 concrete blocks.

Due to the frequency (every 3 or 4 years) of Ion Exchange Resins (IER) packaging campaigns of the two mobile units “Mercure”, the analysis has covered 6 years of production: 2002-2007.

This purpose of this analysis was to provide detailed parameters (see Table 4) for each stream as follows:

- average mass activity of each stream;
- estimate of numbers of each type of packages produced per year on an EPR;
- estimate of numbers of each package to be disposed of per year, after conditioning treatments (high pressure compaction, incineration, melting);

- volume of final packages to be disposed of per year;
- average contact dose rates measurements of waste packages.

Notes:

- It has been conservatively assumed that the physical characteristics of EPR waste arising in operation are essentially the same as the more recent French reactors; notably this applies for the prediction of radioactivity content despite the expected reduction in inventory, as a result of the minimisation of cobalt-60 (cobalt hard facing alloys are suppressed) and silver-110m in the choice of materials in the EPR design.
- Waste arising from the decontamination activities during operation and maintenance [Ref-1] is included in the volumes of the packages.
- Secondary waste produced by incineration and melting units (slag, air filters, etc.) is included in the final volumes of the packages.
- The following should be noted:
  - the wide range of mass activities depending on the type of waste;
  - the overall activity (the sum of short and long-lived nuclides) is about 6.4 TBq per annum (but see note above);
  - the overall volume of raw waste is comparable with that of the final packages, due to high volume reduction obtained with incineration.

	Type of waste	Estimated gross annual volume (m3 of raw waste)	Average mass activity (GBq/te of raw waste)	Density	Estimated gross annual activity (GBq)	Treatments	Packaging on NPP before shipment	Number of packages to be shipped to interim storage (>ILW) or to Drigg and WAMAC (LLW)	Volume of initial packages per year (m3)	Types of final packages to be stored or disposed of	Ratios V. package/ V. raw waste	Volume of final packages (m3)	Number of packages to be stored or disposed of per year upper value
Process waste	Ion-exchange resins from the nuclear island	3	500	1	1500	Embedding	Concrete block 2m3	7,5 (30 each 4 years)	15	Concrete block 2m3	5.18	15.5	8
	SGBS ion-exchange resins (without regeneration)	7.5	0.06	1	0.45	Incineration	Plastic drums 0,2 m3	38	7.6	Heavy metallic drums 0,45 m3	0.04	0.3	1
	Wet sludge (sumps, tanks)	0.5	15	1.2	9	Cementation	Concrete block 2m3	2	4	Concrete block 2m3	6.45	3.2	2
		0.5	< 12		< 7,2	Cementation	Metallic drums 0,2 m3	8	1.6	1/3 Height Disposal container	5.54	2.8	1
	Water filters from effluent treatment	2.5	4800	0.3	3600	Cementation	Concrete block 2m3	6	12	Concrete block 2m3	4.55	11.4	6
		5 2.45	1650	0.3	1200	Cementation	Concrete block 1,23 m3	9	11.1	Concrete block 1,23 m3	4.9	12	9
		0.05	< 12	0.3	< 0,18	Cementation	Metallic drums 0,2 m3	1	0.2	1/3 Height Disposal container	3	0.2	0
	Evaporator concentrates	3	2.67	1	8	Incineration	Tank on truck 5 m3	1	5	No incinerated residue	0	0	0
	Non compactable : air and water filters (85%/15%)	4	0.64	0.4	1	Dismantling	Metallic drums 0,2 m3	20	4	1/3 Height Disposal container	1.38	5.5	1
Operational waste	Pre-compacted operational waste (plastics, clothes, small items…)	50 12.5	0.62	0.4	12.4	Pre compaction on site	Metallic drums 0,2 m3	63	12.6	WAMAC disposal container	0.91	11.4	1
		37.5				Incineration	Plastic drums 0,2 m3	188	37.5	Heavy metallic drums 0,45 m3	0.1	3.8	9
	Oils	2	0.003	0.9	0.005	Incineration	Tank on truck 5 m3	1	5	No incinerated residue	0	0	0
	Scraps	6	4.64	0.5	14	Melting	Metallic boxes 1 m3	6	6	Ingots 0,2 m3	0.08	0.5	3
	Operational waste	0.9	153	0.4	55	Cementation	Concrete block 2m3	3	6	Concrete block 2m3	4.55	4.1	3
		0.1	< 12	0.4	< 0,48	Incineration	Metallic drums 0,2 m3	1	0.2	Heavy metallic drums 0,45 m3	0.1	0	1
Total		**82,5 m3**			**6,4 TBq**				**128 m3**		**Total**	**71 m3**	**45**

Table 4: Operational Waste Treatment, Conditioning and Packaging

Table 5 gives the distribution of LLW and ILW in term of volume of packages to be disposed of or to be stored per year. Some of the LLW packages could be disposed of as VLLW.

	Type of waste	Volume of final packages (m3)	Route (%) at generation time	
			ILW	LLW
Process waste	Ion-exchange resins from the nuclear island	15.5	100%	
	SGBS ion-exchange resins (without regeneration)	0.3		100%
	Wet sludge (sumps, tanks)	3.2	49%	
		2.8		51%
	Water filters from effluent treatment	11.4	100%	
		12	98%	
		0.2		2%
	Evaporator concentrates	0		
	Non compactable : air and water filters (85%/15%)	5.5		100%
Operational waste	Pre-compacted operational waste (plastics, clothes, small items…)	11.4		100%
		3.8		100%
	Oils	0		
	Scraps	0.5		100%
	Operational waste	4.1	93%	
		0		7%
Total		**71 m3**	**46.2 m3**	**24.5 m3**

Table 5: EPR – LLW and ILW distribution

Table 4 left hand side column shows that the estimated gross annual volume of oil and evaporator concentrates is (3+2) m^3 of raw waste. However, due to these wastes being incinerated, the residual wastes are very limited in volume: the residual volume is integrated in the "other operational wastes" which are also incinerated (3.8 m^3 yearly volume of final LLW packages in Tables 4 and 5).

By taking into account a LLW disposal limit of 12 GBq/t of raw waste for the sum of nuclides (excluding α emitters) of the 71 m^3 of packages produced a year, 24.5 m^3 will be accepted at the LLWR or in its equivalent.

This distribution will be different if the limit is applied to the mass of the package; in this instance the ILW package volume decreases from 46.2 m^3 to 30.3 m^3 per year.

3.2.3. Quantification of nuclides and declaration of packages radioactivity content

In this sub-section, a distinction is made between β/γ short lived emitters and pure β or α long lived emitters. The declared radioactivity content is obviously the sum of these two categories.

β/γ short lived emitters

Generally less than ten different emitters are characterised. Gamma spectroscopy is performed on samples of homogeneous waste (evaporator concentrates, ion-exchangers resins, oils, sludge) or directly, with collimation, on the finished packages (concrete containers, drums) for the other heterogeneous waste.

To characterise the heterogeneous waste, another method has been implemented since the 1980s. It is based on the use of 'type spectra' that have been determined by gamma spectroscopy measurements on a large representative population of packages.

The main advantage is the simplification of the characterisation of water filters and Dry Active Waste (DAW). The use of computerised management allows the measurement of package contact dose rates to be converted into radioactivity, through specific computer programs (Microshield, Mercure), thereby converting from mSv/h to GBq.

The EDF network of 58 reactors applies only two types of spectra for heterogeneous waste: S122 for DAW and S222 for filters.

Emitters	S122 DAW and others	S222 Water filters
60Co	39%	23%
58Co	41%	55%
54Mn	4%	9%
65Zn	1%	1%
110mAg	11%	11%
125Sb	1%	-
134Cs	1%	-
137Cs	2%	1%
Total	100%	100%

Table 6: Type spectra used for the β/γ short lived emitters' content in packages of heterogeneous waste

EDF is involved in an ongoing programme of gamma spectroscopy at the request of ANDRA. An average of 10% of concrete containers produced per year is measured in order to confirm the accuracy of these two type spectra.

Pure β and α long lived emitters

For LLW and ILW (short-lived) waste disposal, acceptable activity or activity concentration limits are regulated for individual nuclides and groups of nuclides according to the requirements coming from safety assessment scenarios (for instance: intrusion after a survey period of 300 years post shutdown). In particular, the inventory limits and the maximum concentrations limits of long-lived nuclides (e.g. C-14, Ni-63, Nb-94, Ag-108m and alpha-emitters with a half-life > 30 years) are low. Most of these nuclides are DTM (Difficult To be Measured) and a scaling factor method is applied [Ref-1]. The scaling factor concerns a DTM nuclide and its own key nuclide (generally cobalt-60 or caesium-137).

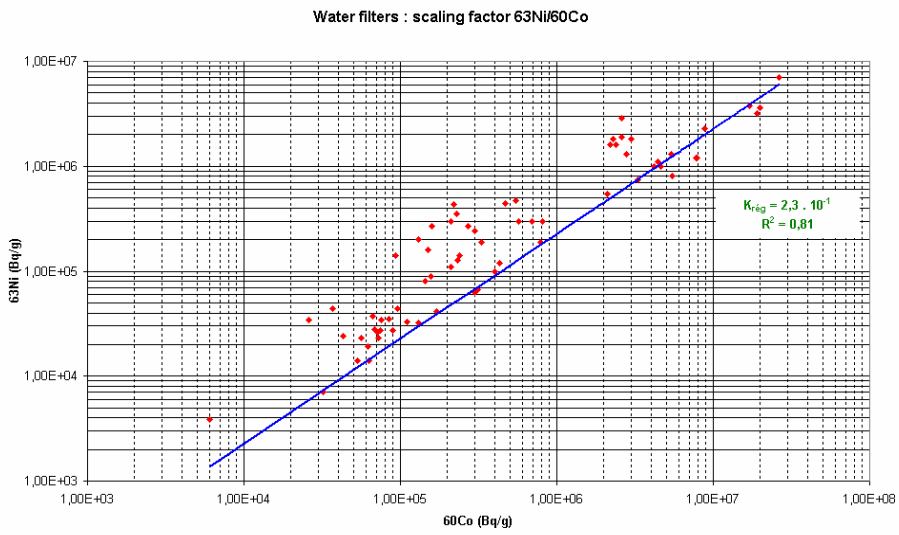

Figure 7: Correlation between nickel-63 and cobalt-60 (scaling factor = 0.23)

Initially, over the period 1992-1995, EDF, with the agreement of ANDRA, implemented the scaling factors given internationally. The same scaling factors were applied for all types of waste. However, following a request from the French safety authorities, in the early 1990s EDF launched a large campaign of sampling and radiochemical analysis on primary coolant, water filters and active ion-exchangers resins from different reactors. Consequently, from 1999 EDF has declared 20 long-lived nuclides (essentially pure β emitters) in packages produced in operation.

In parallel, scaling factors for alpha-emitters (Pu-238+239+240+241, Am-241, Cm-243+244) were also determined. But, they are not used because α emitters are declared only in case of "serious fuel failures" (gross alpha activity > 4 Bq.l^{-1} in the primary circuit).

Type of Nuclide	*Homogenous solidified waste (active ion exchangers' resins)*		*Heterogeneous solidified waste (water filter cartridges)*	
	Evaluated DTM nuclide	*Key nuclide*	*Evaluated DTM nuclide*	*Key nuclide*
CP nuclides	Be-10, C-14, Cl-36, Ca-41, Fe-55, Ni-59, Ni-63, Mo-93, Zr-93, Nb-94, Ag-108m,	Co-60	Be-10, C-14, Cl-36, Ca-41, Fe-55, Ni-59, Ni-63, Mo-93, Zr-93, Nb-94, Ag-108m	Co-60
FP nuclides	Se-79, Sr-90, Tc-99, Pd-107, Sn-121m, Sn-126, I-129, Cs-135, Sm-151, Pu-241 (β)	Cs-137	Se-79, Tc-99, Pd-107, Sn-121m, Sn-126, I-129, Cs-135, Sm-151, Pu-241 (β)	Cs-137
			Sr-90	Co-60
Alpha-emitting nuclides	Total alpha-emitting nuclides and Pu-238+239+240+241 Am-241, Cm-243+244	Co-60	Total alpha-emitting nuclides and Pu-238+239+240+241 Am-241, Cm-243+244	Co-60

Table 7: Evaluated nuclides and selection of key nuclides

At the present time, scaling factors validated in 1999 are applied. Those obtained in 2004 and after are not yet validated.

The use of Co-60 as the key nuclide for the declaration of the global alpha radioactivity in waste (e.g. arising from small fuel pin failures) is a consequence of the stronger correlations found in Co-60 (filters and ion exchangers) than those obtained with Cs-137.

During the transition to shutdown, a partial dissolution of actinides deposited on the circuit occurs in the same manner as it does for Co-60. The increase in activity of soluble to insoluble Co-60 occurs at the same rate as that for the global alpha activity of the primary circuit water despite an increase in the activity in solution by a factor of greater than 10.

IER

Nuclides	Key	SF 1999
Be^{10}	Co^{60}	**2 E-07**
C^{14}	Co^{60}	**1.8 E-02**
Cl^{36}	Co^{60}	**1 E-05**
Ca^{41}	Co^{60}	**5 E-06**
Fe^{55}	Co^{60}	**1.4 E-01**
Ni^{59}	Co^{60}	**1.1 E-03**
Ni^{63}	Co^{60}	**1.4 E+00**
Se^{79}	Cs^{137}	**4 E-06**
Sr^{90}	Cs^{137}	**2.3 E-03**
Mo^{93}	Co^{60}	**1 E-06**
Zr^{93}	Co^{60}	**5 E-07**
Nb^{94}	Co^{60}	**1.2 E-04**
Tc^{99}	Cs^{137}	**1 E-05**
Pd^{107}	Cs^{137}	**1 E-07**
Ag^{108m}	Co^{60}	**1 E-03**
Sn^{121m}	Cs^{137}	**2 E-05**
Sn^{126}	Cs^{137}	**9 E-06**
I^{129}	Cs^{137}	**1 E-06**
Cs^{135}	Cs^{137}	**5 E-06**
Sm^{151}	Cs^{137}	**7 E-04**

Water filters & Others

Nuclides	Key	SF 1999
Be^{10}	Co^{60}	**2 E-07**
C^{14}	Co^{60}	**1.1 E-02**
Cl^{36}	Co^{60}	**1 E-06**
Ca^{41}	Co^{60}	**5 E-06**
Fe^{55}	Co^{60}	**2.1 E+00**
Ni^{59}	Co^{60}	**5.3 E-04**
Ni^{63}	Co^{60}	**2.3 E-01**
Se^{79}	Cs^{137}	**4 E-06**
Sr^{90}	Co^{60}	**2.6 E-02**
Mo^{93}	Co^{60}	**1 E-06**
Zr^{93}	Co^{60}	**5 E-05**
Nb^{94}	Co^{60}	**1.3 E-04**
Tc^{99}	Cs^{137}	**4.2 E-04**
Pd^{107}	Cs^{137}	**1 E-05**
Ag^{108m}	Co^{60}	**1 E-03**
Sn^{121m}	Cs^{137}	**2 E-05**
Sn^{126}	Cs^{137}	**9 E-06**
I^{129}	Cs^{137}	**1 E-06**
Cs^{135}	Cs^{137}	**3 E-06**
Sm^{151}	Cs^{137}	**4 E-03**

Table 8: Evaluated nuclides, selection of key nuclides and scaling factors applied for the long-lived emitters' declaration (IER, left)

Table 9: Evaluated nuclides, selection of key nuclides and scaling factors applied for the long-lived emitters' declaration (Water filters and others, right)

3.2.4. Physical-chemical characteristics of waste

Since 2000, French specifications for the acceptance of LLW/ILW waste packages in the Aube centre have required the identification and quantification of a dozen chemical toxins and twenty complexing agents.

Chemical toxin thresholds have been specified. They are expressed in ppm (parts per million) and range from 1 ppm (Se, Cd, Hg, CN^-, Cr^{VI}) to 100 ppm (Cr_{tot}, Pb).

There is no defined threshold for complexing agents but their presence has to be declared, specifically in solid waste resulting from chemical decontamination or cleaning processes (e.g. poly-carboxylic acids, detergents).

According to the chemical toxin thresholds, toxin spectra have been defined for most of the waste streams.

Chemical toxins (*)	IER		Sludges		Water filters		DAW	
	1	2	1	2	1	2	1	2
B	9000	3700	1000	400	5000	250	100	20
Hg	20	10	5	1.5				
Pb			335	125	425	20		
Ni			165	60	210	10		
Cr tot			190	70	240	10		
Sb			5	1.5			1000	200
Cd			10	3	10	0.5		
Hg			5	1.5				

Table 10: Chemical toxins declared in active waste

(*) Chemical toxins declared because respective thresholds exceeded.

Columns 1: concentration in ppm related to the raw waste

Columns 2: concentration in grammes per waste package

Apart from these spectra, a lot of specific waste is identified: batteries, office IT devices (e.g. screens, keyboards, printers), electronic cards and are analysed at the time of arising.

3.2.5. Impact of the decay on the waste

It is interesting to analyse the impact of the decay (30 years), specifically on packages of DAW (and sludge), water filters and IER, as a function of their short and long-lived emitters content.

	IER		DAW and sludge		Water filters	
Nuclides	Now	Decay 30 y	Now	Decay 30 y	Now	Decay 30 y
60Co	21,1%	1,3%	20,3%	7,5%	14,9%	8,0%
58Co	13,6%	0,0%	21,3%	0,0%	35,7%	0,0%
54Mn	4,6%	0,0%	2,1%	0,0%	5,8%	0,0%
65Zn	0,0%	0,0%	0,5%	0,0%	0,6%	0,0%
110mAg	6,0%	0,0%	5,7%	0,0%	7,1%	0,0%
125Sb	0,0%	0,0%	0,5%	0,0%	0,0%	0,0%
134Cs	5,8%	0,0%	0,5%	0,0%	0,0%	0,0%
137Cs	14,9%	23,0%	1,0%	9,9%	0,6%	9,0%
22Na	1,0%	0,0%	0,0%	0,0%	0,0%	0,0%
C14	0,4%	1,2%	0,2%	4,2%	0,2%	4,5%
Fe55	3,0%	0,0%	42,6%	0,4%	31,4%	0,4%
Ni59	0,0%	0,1%	0,0%	0,2%	0,0%	0,2%
Ni63	29,6%	74,3%	4,7%	72,3%	3,4%	77,1%
Sr90	0,0%	0,1%	0,5%	4,9%	0,0%	0,2%
Nb94	0,0%	0,0%	0,0%	0,1%	0,0%	0,1%
Ag108m	0,0%	0,1%	0,0%	0,4%	0,0%	0,4%
Sm151	0,0%	0,0%	0,0%	0,1%	0,0%	0,1%

Table 11: Evolution of average spectra of IER, DAW and sludge, water filters with 30 years of decay

Notes:

- Other long-lived emitters are declared but they are not taken into account in these tables due to their low contents.

- It can be noted that after 30 years of decay the main nuclide is nickel-63.

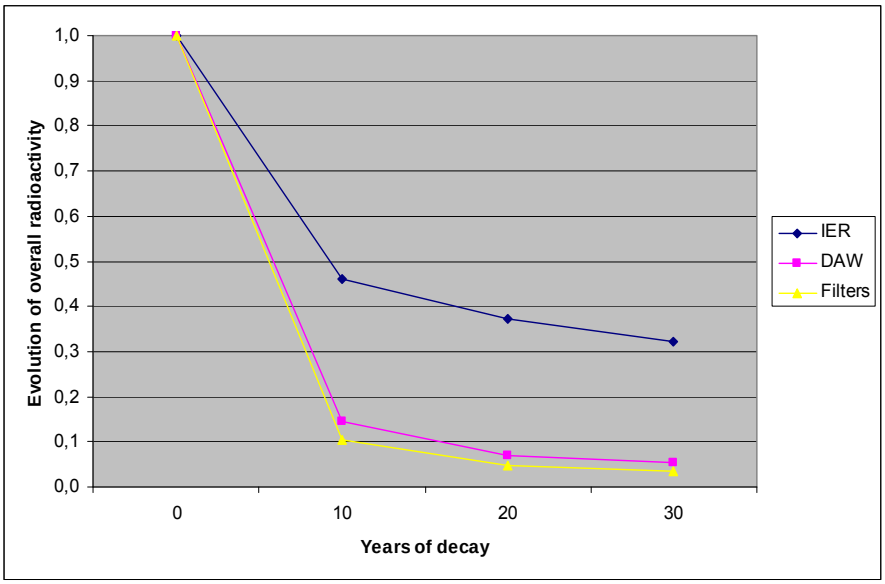

Figure 8: Evolution of overall radioactivity declared

These graphics show that a lot of packages produced could meet the LLW acceptance limit (12 GBq/t for β/γ emitters). By considering the raw waste mass and package mass, those distributions change after 30 years of decay such that 35.6 m^3 or 56.1 m^3 respectively of packages could potentially be considered as LLW.

3.2.6. Large radioactive waste items

Improvements and provisions were included in the EPR design in order to avoid replacement of large one-off items such as the Reactor Pressure Vessel (RPV) head and Steam Generators (SGs). The improvements are mainly to prevent 600 alloy corrosion, but also design changes in order to reduce phenomena such as vibrational wear. Moreover, the implementation of good chemistry management during operation should prevent the build up of crud and activity due to contamination inside the tubes, over the operating life of the SGs.

Should a failure occur on a RPV head or should a SG need replacement, the activity would be carefully planned and the best way to dispose of the failed item would be examined. There is significant operating experience feedback on the replacement of heavy components in the current French fleet and such operations are performed on a case-by-case basis; the construction of a dedicated interim storage facility, if needed, and the design of appropriate treatment and conditioning are studied.

The characteristics of such waste are presented in PCER Sub-chapter 5.2. The RPV and SG are partly LLW and partly VLLW just after the reactor has finally shutdown; this takes into account the overall decontamination of the primary circuit subsequent to dismantling. Several methods of packaging could be chosen, such as cutting these items in pieces to place them in standard HHISO 20' containers or designing dedicated containers. If authorised at the time processing takes place, segregation can also be envisaged between components which would go to the LLW / VLLW repository and other parts which could be declassified and either sent for recycling (e.g. melting as shielding blocks) or shipped to a conventional waste repository.

The methodology, which would be retained several decades from now, would take into account the present and future feedback experience of reactor decommissioning.

3.3. CHARACTERISTICS OF PACKAGED SOLID WASTE FOR OPTIONS TO THE REFERENCE CASE

The Solid Radioactive Waste Strategy Report (SRWSR) [Ref-1] further describes the waste streams and alternative options to the reference case for the processing and packaging of operational waste based on experience from other EPR plants and other utility practices.

4. DETERMINATION OF QUANTITATIVE TARGETS FOR LIQUID AND GASEOUS DISCHARGES

Two types of quantitative target are addressed:

- the concept of “expected performance excluding contingencies”, which corresponds to estimated realistic discharges under nominal operating conditions without significant contingencies; or

- the concept of "maximum discharge values", which corresponds to the estimated maximum discharges from the unit, given normal operating contingencies and transients. The transients taken into account do not fall under the incident or accident domain.

The EPR expected performance is derived from recent operating experience feedback from the 1300 MW(e) French facilities, taking credit for certain design features and taking into account guaranteed quantifiable gains during the reference period, as explained below.

The period 2001 - 2003 was chosen as it is sufficiently recent to be representative of the realistic performance of the facilities currently in operation, reported according to new accounting methods, and it is also a sufficiently long period to average out the impact of variations expected over the operating cycle.

Using the 8 plants concerned over 3 years, the statistical distributions for the 8 plants (which are the averages for each site over the 3 years calculated per unit) is used as a reference. This per-site distribution enables the “site operation” effect to be distinguished and a base-line representative of performance averaged over time to be obtained.

The estimates for EPR expected performance excluding contingencies, i.e. the estimated realistic discharge, is, wherever possible, based on design improvements and source term calculations. When meaningful, this gain is applied to the first quartile of the operating experience feedback distribution of the 1300 MW(e) units (excluding some specific cases).

N.B.: due to the cumulative effects of increased power and an increased availability coefficient, for an equal absolute discharge value, the EPR discharge in relation to the energy produced is 25% less than 1300 MW(e) discharge.

5. GENERAL APPROACH FOR THE DETERMINATION OF RADIOACTIVE LIQUID AND GASEOUS QUANTITATIVE TARGETS

The following sections present the approach undertaken to justify the EPR liquid and gaseous annual discharges, and determine monthly discharges for the different families of radionuclides. In all the following paragraphs, the "annual expected performance without contingency" corresponds to the lowest annual discharges (whether liquid or gaseous) that can be expected from one EPR unit. It is a very ambitious concept as it requires that all systems function to their optimised level and that no contingency or operational failure is encountered. In other words, the annual expected performance without contingency can be considered to be the minimum annual discharge possible during all phases of normal operation of the reactor (including for example start-up and shutdown phases).

The impact of the contingencies on the predicted future discharges is essential as it has been recognised that reasonable headroom needs to be added to the expected performance without contingency in order to determine an adequate maximum discharge value. This headroom needs to be carefully assessed in order to allow for operational difficulties, and so that the discharge limit is not exceeded, which would not only be unacceptable but would also have a strong influence on the public perception of nuclear safety. On the other hand, overly generous headroom would lead to a high value of discharge limit, which, if such a discharge occurred, could subsequently lead to a high public estimated dose.

This approach is different to the approach undertaken in the past for the determination of limits for existing reactors. Indeed, in these cases, the discharge authorisation limits for radioactive substances were determined retrospectively from the calculation on the dose received. This approach did not take into account the reactor performance and thus often provided large headroom between the actual discharge and the limit. Indeed, the first decrees implemented in France in 1966 and 1976 regarding ionising radiations explicitly referred to sanitary considerations and the annual limits and volumetric activities added to the environment allowed to be discharged guaranteed the protection of the populations exposed to both liquid and gaseous discharges. The maximum dose received to the whole body by a member of the public was 5 mSv/y (reduced to 1 mSv/y currently). The approach adopted in France since the 26th November 1999 is different and only focuses on the basis of the performance of the installations, in line with the Best Available Techniques available and not entailing any excessive costs. The new authorisation discharge limits have thus been based on Operating Experience Feedback (OEF) data which shows, in line with the ALARA and BAT principles, a large reduction of the activities and volumes of effluents discharged (except tritium) due to the optimisation of the discharges of the existing units.

It thus seems possible to reduce the annual site discharge limits to be as close as possible to the actual site discharges. The limits now in force or those submitted to the French regulators are considered to be as low as possible to ensure normal operation of the facility while providing maximum protection of the populations living nearby. Even at their limit level, the impact of the discharges on health would be very limited and much lower than the 1 mSv/y dose threshold for populations living nearby.

Following the determination of the expected performance without contingency, the impact of a number of contingencies on the releases was estimated, based on operating experience feedback from some existing units. In particular, operating experience feedback data over the period 2002-2007 of two 1300 MW(e) sites, Flamanville (2 units) and Paluel (4 units), were used. These two sites have been chosen as their liquid and gaseous discharges are consistently in the average of all the 1300 MW(e) discharges and therefore are considered to be representative of all the 1300 MW(e) sites. In addition, they are coastal sites. Other units have been considered for specific radionuclides. In particular, data from French N4 units have been used for the determination of gaseous tritium values (see section 7.2) and data from German KONVOI units have been used for the determination of the gaseous C-14 values (see section 7.3).

Operating experience feedback data are given per unit for the gaseous discharges (recorded for each stack). The data for the liquid discharges are given for the whole site as the final storage tanks are generally shared between the different units on site, and therefore caution is needed when interpreting the liquid discharge data as they do not generally closely match the production rate of the radionuclide considered.

In addition to the operating experience feedback data used, and in order to fully understand the role of site management choices regarding discharges and the contingencies associated with some of the discharges, extensive discussions with the operational staff at the Penly site and with the EDF Division de Production Nucléaire (DPN, which gathers information for all the French fleet) have taken place. In particular, this was to determine the site management factors influencing the liquid and gaseous discharges. The representative values for the discharges of 1300 MW(e) reactors were then adapted to the EPR, taking into account design changes and other criteria to assess the predicted future annual and monthly discharge. Finally, operating experience feedback from a number of other sites, known for having encountered contingencies such as fuel leaks, was used in order to determine the impact of such events on the overall liquid and gaseous discharges.

Overall, the combination of the expected performance without contingency and of the impact of the contingencies on the discharges represents the maximum discharge under normal operating conditions.

From a monthly point of view, the monthly discharge is not necessarily one twelfth of the “annual expected performance without contingency” or of the annual maximum discharge value as the discharge profile of most radionuclides is not flat over the whole fuel cycle (or over a year) and therefore, even in normal operating conditions, some months will have higher discharges than others.

The EPR has been presented as having a better environmental performance compared to the existing reactors; it is hence expected that the EPR discharge authorisations should be lower than those of the existing plants. Despite this, due to its higher power production, its fuel management, its higher availability rate and its overall operational management, it is undeniable that the overall production of some radionuclides from the EPR (rather than the production normalised per GWh produced) will be higher than for some of the existing reactors.

6. LIQUID RADIOACTIVE EFFLUENT DISCHARGES

6.1. EURATOM RECOMMENDATION AND FRENCH PRACTICE

The EURATOM recommendation 2004/2/Euratom [Ref-1] recommends that the discharge activity of all the following radionuclides should be assessed for liquid discharges from nuclear power reactors: tritium*, S-35* (for gas-cooled-type reactors only), Cr-51, Mn-54, Fe-55, Fe-59, Co-58, Co-60*, Ni-63, Zn-65, Sr-89, Sr-90*, Zr-95, Nb-95, Ru-103, Ru-106, Ag-110m, Sb-122, Te-123m, Sb-124, Sb-125, I-131, Cs-134, Cs-137*, Ba-140, La-140, Ce-141, Ce-144, Pu-238, Pu-239 + Pu-240*, Am-241*, Cm-242, Cm-243, Cm-244. If nuclide-specific information on alpha-emitters is not available, then total-alpha activity should be reported. In addition, the recommendation states that "Member States should report the following information on radioactive discharges to the Commission (…):

- annual discharge values for each radionuclide listed above for which there is at least one measurement outcome above the decision threshold in the period considered, or for which at least a calculated assessment has been made in the same period;
- for each key nuclide (marked with a * in the above list), the highest value of the detection limit that has been obtained among all the measurements for the period considered;
- estimates of radionuclide discharges based on calculation, as a substitute for measurement, when measurement is not technically feasible (…)".

The practice currently implemented in France, since 2002, is to report the liquid discharges from nuclear power stations in 4 categories:

- tritium;
- carbon-14;
- iodine isotopes; and
- other radionuclides.

Essentially, the iodine category only includes I-131, and all other fission and activation products (Cr-51, Mn-54, Co-58, Co-60, Ni-63, Ag-110m, Te-123m, Sb-124, Sb-125, Cs-134, Cs-137) are reported under the "other radionuclides" category. In addition, French regulations do not allow the discharge of any man-made alpha activity from nuclear power stations and therefore a measurement is carried out before discharge to ensure the absence of such products (in particular the key nuclides Pu-239 + Pu-240 and Am-241). Thus, and according to EURATOM regulations, the measurements of alpha-emitting radionuclides are not reported as they are consistently below the decision threshold. Finally, and according to the last point stated above, the C-14 discharges are estimated based on calculations rather than routinely measured. Regular reporting of measured C-14 values has only recently started at some of the French power stations, in order to determine more accurately the actual C-14 discharges (discrepancies can be observed between measured and calculated values, see section 6.3.2). Overall, most of the key radionuclides from the EURATOM recommendation are monitored in France, except for Sr-90. Detection of Sr-90 is expensive and not very reliable in comparison to the detection of other fission products (FP) such as Cs-137, which can give an indication of fuel leak data more easily than Sr-90. When it has been monitored, the levels recorded in France were below the limit of detection. In the UK, compliance with the EURATOM recommendation is satisfied by utilities reporting through the Environment Agency Pollution Inventory database, which may be accessed through their web site. At Sizewell B, Sr-90 is assessed once per year from the bulk of four quarterly samples and measurements are consistently less than the limit of detection.

Considering all the above, it was decided that the practice currently in force for the reporting of liquid radioactive discharges is in agreement with the EURATOM Recommendation and that these practices should be those in place for the UK EPR.

The production and treatment of liquid effluent is described in Sub-chapter 6.2 of the PCER. In summary, liquid effluents fall into one of three categories:

- primary liquid effluents. These effluents are comprised of liquid leaked or drained from the primary coolant water, or water from circuits containing the primary coolant and discharge to downstream treatment systems in response to specific requirements;
- spent liquid effluent. These effluents are of three different types: process drains, chemical drains or floor drains;
- drainage water from the turbine hall. In particular, these effluents include blowdown water from the steam generators, along with water drained from the Turbine Hall that comes from leakage, and from draining and emptying the secondary circuit.

More details are given in Sub-chapters 6.2 and 6.4 of the PCER.

6.2. LIQUID DISCHARGES OF TRITIUM

6.2.1. Production

In pressurised water reactors, the sources of tritium which may contaminate the primary system can be classified into two categories:

- direct sources, where the tritium is produced directly in the coolant fluid;
- indirect sources where physical barriers exist isolating them from the coolant.

6.2.1.1. Direct sources

Direct sources of tritium mainly originate from nuclear reactions in some elements contained in the primary system water. The production reactions are as follows [Ref-1]:

- B-10 (n, 2α) H-3 in the reactivity control boron, introduced in the form of boric acid;
- Li-6 (n, α) H-3 in the lithium used in the form of lithium hydroxide (LiOH) to control the $pH_{300°C}$ in the primary coolant;
- H-2 (n, γ) H-3 in the deuterium naturally present in the primary water and also resulting from the neutron reaction with hydrogen H-1.

The boron used as a neutron absorber to limit core reactivity, is injected in the form of boric acid. The lithium is injected in the form of lithium hydroxide which is a strong base (alkali) used to control the $pH_{300°C}$ to limit corrosion of the components in the primary system. Its concentration is linked to that of the boron.

6.2.1.2. Indirect sources

Indirect sources of tritium originate in the fuel itself, by means of ternary fission reactions, the boron contained in the burnable poison rods or the control rods via the reaction B-10 (n, 2α) H-3, the helium pressurising the fuel rods via the reaction He-3 (n, p) H-3, and the beryllium from the secondary neutron source Sb-Be rods. Although the fuel is the main source of tritium (about 600 TBq/year for a 900 MW(e) PWR using UO_2, 700 TBq/year using MOX, 900 TBq/year for a 1300 MW(e) PWR and 1000 TBq/year for a 1450 MW(e) PWR), its contribution to tritium contamination of the primary coolant remains very low. Tritium is released from the fuels rods at a rate evaluated at less than 10^{-2}%. The very low leakage from the fuel rods is due to the high affinity of the tritium for the zirconium making up the cladding and its very low diffusivity in the oxide formed on their surface (zirconia). This behaviour is not changed by adopting M5 as the cladding material. The contribution of the undamaged fuel is about 0.15 GBq/EFPD for a 900 MW(e) PWR and 0.2 GBq/EFPD for a 1300 MW(e) or 1450 MW(e) PWR. It is therefore considered negligible at far less than 1 TBq/year.

Moreover, it has been shown that the B_4C from the control rods in the 1300 MW(e) PWRs does not release tritium in normal operating conditions [Ref-1].

The **secondary neutron source rods** represent a potentially significant source of contamination of the primary coolant by tritium. The role of these rods is to demonstrate the availability of the Source Neutron Channels by ensuring a count rate higher than the background, in accordance with the Operating Technical Specifications. The secondary source rods are made up of a mixture of cold-sintered Sb–Be, which are particularly tritium-breeding in a neutron flux. These rods have a stainless steel cladding reputedly highly permeable to tritium (99% in normal operating temperature ranges). The contribution of these secondary source rods was quantified during operating cycles to validate the tritium source term. In 1300 MW(e) PWRs, where four secondary source rods are maintained in the core, their contribution is between 10 GBq/EFPD and 30 GBq/EFPD or **3 to 10 TBq/year**. This contribution represents up to 25% to 30% of the average total annual production of tritium for the 1300 MW(e) and N4 facilities, with current management.

6.2.1.3. Means of reducing tritium production for the EPR

In EDF PWRs, the tritium discharged is mainly formed from direct sources and the secondary neutron source rods. As a consequence, the following avenues were explored.

6.2.1.3.1. Burnable poison and boron concentration

The boron concentration can be reduced by increasing the use of burnable poisons. By reducing the required boron concentration, the associated production of tritium is reduced.

For the EPR, gadolinium was chosen as the burnable poison. This poison consists of mixing gadolinium oxide (Gd_2O_3) with the UO_2 in the pellets of some of the fuel rods. Gd_2O_3 degrades the thermal conductivity of the pellets into which it is introduced. For this reason, they are included in rods with enrichment lower than the rest of the assembly. This results in a “residual” penalty, which may be high if the number of poisoned rods is high.

Increasing the design output to 4500 MWth required some changes in fuel management including an increase in the number of new assemblies loaded to conserve the same natural cycle length despite a power increase of 6%. The tritium source term was reduced by optimising the gadolinium load [Ref-1]. There is no general quantification of this as the reduction is dependent on the fuel management approach adopted.

The optimisation approach was applied to UO_2 and MOX 18 months IN/OUT options. Particular attention was also paid to the study of changes to the UO_2 22 month option: the gadolinium loads for the options concerned were increased and optimised, in order to reduce the boron concentration and consequently the production of tritium while controlling the equivalent full power day (EFPD) losses generated.

This action led to a drop in the maximum annual production of tritium by the EPR, despite the adverse effect of increased power.

6.2.1.3.2. Secondary source rods

The tritium source term calculated here takes into account the contribution of the secondary neutron source rods, estimated at **9 TBq/year**.

To reduce the contribution of these rods, two solutions could theoretically be envisaged, replacing the stainless steel cladding of these rods with a zirconium-based alloy or removing the secondary source rods altogether.

An analysis of removal of the secondary source rods for the EPR is currently in progress. The initial operational data will be available on start-up of the Finnish EPR reactor Olkiluoto 3. These data will only apply for a new core with primary sources, and so may not be sufficient to confirm the feasibility of any removal of the secondary source rods. There is not yet sufficient information to support this option.

The use of zirconium-based cladding for the secondary source rods has not been chosen, as it would have a negative environmental impact due to its incompatibility with the current lifetime requirement for these rods (15 years):

- it would require the replacement of these rods after five years of use. Such a replacement frequency would mean an increase in the quantity of beryllium in the waste due to increasing the number of replacements;

- in addition, the activation of these rods under flux leads to the formation principally of antimony-124, antimony-125 and cobalt-60. The activity of these radio-isotopes after five years of irradiation goes from several hundreds of TBq to several tens of thousands of TBq for four rods of type 1300 MW(e). As saturation activity is reached before five years, early replacement of the secondary source rods would multiply the total activity of the waste associated with the use of these rods by the number of replacements.

6.2.1.3.3. Lithium

To reduce the production of tritium from lithium, the lithium hydroxide used to chemically treat the primary coolant was depleted of Li-6. The specification of the isotopic composition of the make-up lithium is at least 99.90 at.% of Li-7. In comparison, the isotopic composition of natural lithium is 91.47 at.% of Li-7.

Currently, the boron-lithium ratio usually applied at EDF facilities is known as “low lithium”. The maximum lithium concentration is 2.2ppm in this ratio. Reducing the lithium concentration of the primary system would lower the $pH_{300°C}$, leading to an increase in the production of corrosion products and of the contamination which would result, and hence increase dose to the workers, and perhaps liquid discharges.

To offset the drop in the $pH_{300°C}$ due to an increase in the boron concentration inherent in the EPR fuel cycle of at least 18 months, an increase in the lithium concentration has been envisaged by applying new B-Li ratios. For the EPR, different ratios have been envisaged, up to a concentration of 6 ppm of lithium at the beginning of life.

Three boron-lithium ratios have been studied to evaluate the tritium source term, for EPR fuel management options:

- A “Top of operating range” maximum lithium concentration fixed at 2.2ppm of Li at start of cycle (maximum lithium concentration currently recommended), then linear decay to 0.6ppm from a boron concentration of 560ppm. This chemistry is called “low lithium";

- A “Top of operating range” maximum lithium concentration fixed at 3.5ppm of Li at start of cycle, then linear decay to 0.6 ppm from a boron concentration of 860ppm. This chemistry is called “high lithium"; It is different from “DUO” chemistry in that there is only one step at 3.5ppm of lithium, followed by a linear decrease. High lithium chemistry is not applied to current management options in use in the facilities;

- A B–Li ratio with constant $pH_{300°C}$, with a maximum lithium concentration which may reach 6ppm at the start of the cycle.

“Top of operating range” chemistry means that the maximum lithium concentration values specified are assumed.

Other ways of reducing tritium production include the use of highly depleted lithium (99.99% Li-7), or additional use of enriched boron (e.g. 37% of B-10 instead of natural 20% B-10). The pH compensation would then use less lithium and may reduce further the production of tritium.

Currently, a ‘high lithium’ B-Li ratio is expected on the EPR, with a target $pH_{300°C}$ value of 7.2 and a maximum lithium concentration of 4 ppm at the start of cycle (see Sub-chapter 5.5 of the PCSR).

6.2.1.4. Estimation of the tritium source term

The production of tritium is an almost direct function of the energy produced (excluding the significant contribution of the secondary source rods).

To **estimate maximum production,** a production coefficient (ratio of the number of EFPD operation to the number of effective days) of 100% is used and, considering that the annual tritium production of a unit is maximised if its cycle starts on 1st January (maximum boron concentration), and for the envelope of lithium concentration at 6ppm and UO_2-IO-22 month management: the maximum tritium production is **75 TBq/year.** The importance of starting the cycle on the 1st January is to ensure that maximum discharges are attained (discharge authorisations run in France on calendar year rather than rolling 12 months).

Fuel-management method	**Maximum annual production TBq Low lithium chemistry 99.90% Li-7**	**Maximum annual production TBq High lithium chemistry 99.90% Li-7**	
	2.2 ppm Li	3.5 ppm Li	6 ppm Li
UO_2-IO-18 months	57+9	60+9	62+9
UO_2-IO-22 months	60+9	63+9	**75=66+9**
MOX-IO-18 months	58+9	61+9	63+9

Table 12: Maximum annual production of tritium of a unit for optimised fuel management methods (with secondary source rods) [Ref-1].

In order to estimate the average production, the production coefficient assumed is taken as 91% and the start of cycle is randomly spread over the year, and the median hypothesis of a lithium concentration at 3.5ppm for UO_2-IO-18 month management: the average tritium production is **52TBq / year.**

Fuel-management method	**Average annual Production TBq Low lithium chemistry 99.90% Li-7**	**Average annual Production TBq High lithium chemistry 99.90% Li-7**	
	2.2 ppm Li	3.5 ppm Li	6 ppm Li
UO_2-IO-18 months	41+9	**52=43+9**	45+9
UO_2-IO-22 months	40+9	42+9	43+9
MOX-IO-18 months	42+9	44+9	46+9

Table 13: Average annual production of tritium of a unit for optimised fuel management methods (with secondary source rods) [Ref-1].

6.2.2. Liquid discharges of tritium

6.2.2.1. Estimate of expected performance and maximum discharge values

Tritium discharges are almost completely in liquid form. The discharge of liquid tritium is associated with the control of the tritium concentration in the primary circuit (see Figure 9). Indeed, in order to limit the tritium gaseous discharges both when opening the reactor core and around the storage pools (gaseous tritium is present due to evaporation of the storage pools), and hence improve the radiological protection, it is essential to limit the concentration of tritium in the primary coolant.

There are currently no processes implemented on an industrial scale for the treatment of tritium in liquid phase, and therefore all liquid tritium produced is discharged. In addition, because the half-life of this element is more than 12 years, it is not possible to store all the liquid tritium produced for decay before discharge, as the volumes involved would be too large. This would also increase the risk of uncontrolled gaseous tritium discharge due to evaporation of the storage tanks.

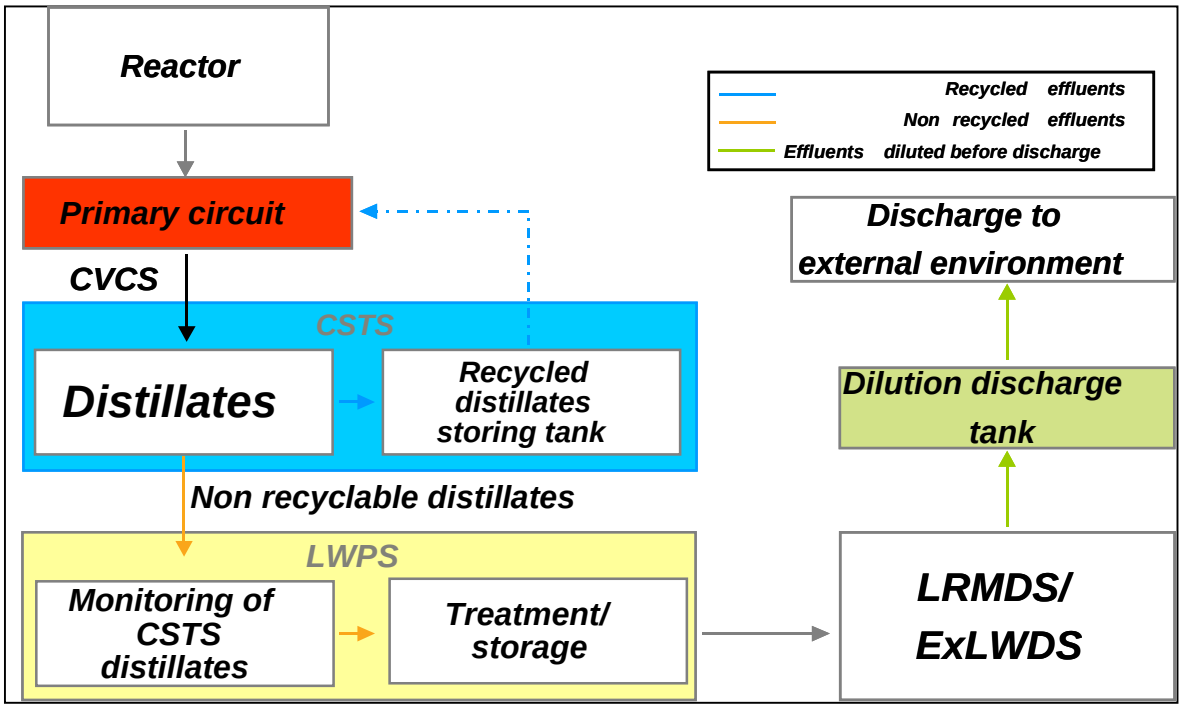

Figure 9: EPR liquid tritium production and discharge process

In practice, a maximum target tritium concentration in the primary fluid is determined and discharge of the excess liquid in the system is necessary. The calculations carried out on the estimation of the source term have determined an expected annual discharge performance of 52 TBq/y, and a maximum discharge value of 75 TBq/y (see section 6.2.1.4).

6.2.2.2. Analysis of Operating Experience Feedback and factors influencing the annual liquid tritium discharges

The current annual discharge limits for liquid tritium for 1300 MW(e) sites are as follows:

- 60 TBq/y for Flamanville site (2-unit site);

- 120 TBq/y for Paluel site (4-unit site).

The 60 TBq/y limit is currently being reviewed at Flamanville as it does not provide adequate margin to allow for operational contingencies. Thus, the authorisation request for water intake and liquid and gaseous releases of the Flamanville site requires this limit to be increased to 80 TBq/y. Appendix A-1 and Appendix A-2 give the annual profiles for the liquid tritium discharges for the Flamanville and Paluel sites over the periods 2002-2007, both as total and as percentages of the annual site discharge limits.

It has already been established that the tritium production is closely linked to the power produced in a PWR. As such, comparison of discharges as percentages of the annual site limit is most relevant, rather than overall discharge data. Indeed, these limits for the existing 1300 MW(e) reactors considered have been established on the basis of source term calculations and operating experience feedback, unlike the EPR proposed maximum discharge values based only on calculations (no OEF is available for the EPR).

The current fleet management policy is to discharge all tritium produced, in order to avoid concentration of tritium in the primary circuit and in particular all the radiological protection issues associated with it. Therefore, it should be expected that annual discharges will be close to 100% of the annual site discharge limits. However, operating experience feedback data provide evidence that sites may struggle to follow the fleet management policy of discharging all tritium produced, due to the very small margin allowed between annual production and the annual site discharge limit. Thus, most sites manage their discharges so that there remains reasonable headroom to account for any potential contingencies and therefore aim to discharge around 80% of their annual site discharge limit. This, in particular, is the case at Paluel over the period considered, as shown in Appendix A-2. At Flamanville, the margin provided by the current limit (60 TBq/y) does not provide sufficient headroom to allow for potential contingency, as shown in Appendix A-1 where discharges are very close to 100% of the annual site discharge limit. If the discharge limit authorisation is increased as required to 80 TBq/y, the site will be able to manage its liquid tritium discharges so that there remains reasonable headroom to account for any potential contingencies and should be able to discharge all tritium produced, as the fleet management policy requires.

Operational contingencies that may impact the discharge intermittently include for example:

- unplanned shutdown. Since the production of tritium is almost proportional to the energy production, it is evident that large fluctuations during a fuel cycle are observed. In particular, the annual discharges of liquid tritium are much lower if a reactor has been shutdown during the year (either for refuelling or for unplanned shutdown) than if it has been operational throughout the year. In addition, variation over the fuel cycle also impact annual discharges; as tritium production is higher at the beginning of a cycle than at the end (higher boron and lithium concentration in the primary circuit), discharges are also generally higher in the first months of a cycle before falling off. The starting point of a cycle in the year thus impacts the overall annual discharge (over a calendar year). This issue is not necessarily seen if the discharges are considered over a rolling year;

- fuel leaks, implying a higher tritium concentration in the primary circuit than usual and therefore higher tritium discharges;

- one (or several) T (0KER [LRMDS]) storage tanks unavailable for use, for example following an unexpected contamination of the effluent, which cannot in turn be discharged.

In addition, due to the lack of operating experience feedback data for the EPR, in particular concerning the combustion mode used, an additional margin was added to the EPR calculated expected performance value. For example, since 1999, the GEMMES fuel, which is more enriched in U-235 than the previous fuel, has been used. Because of the higher enrichment of this fuel, the boric concentration of the primary circuit needs to be higher and consequently the tritium production is also higher. This impacted the tritium activities discharged since 2000 (see Appendix A-1 and Appendix A-3). This is the reason why the most recent authorisation request for water intake and liquid and gaseous releases for the Flamanville site (submitted in 2006) required an increase from 60 TBq/y to 80 TBq/y for the annual limit for the discharges of liquid tritium. This adjustment of the annual limit for discharge of tritium in liquid form was motivated by reasons associated with GEMMES fuel management.

As such, it was established above that under the most likely fuel management scenario considered for the EPR (18 months UO2-IO, Li concentration of 3.5 ppm, production coefficient of 91% and presence of secondary source rods), the EPR annual expected production of liquid tritium without contingency would be 52 TBq/y (see section 6.2.1.4). Considering the Operating Experience Feedback above and the increase in power production, this value seems in line with that of the 1300 MW(e) fleet. In addition, the maximum discharge value of 75 TBq/y, calculated considering a "worst case scenario" (production coefficient of 100%, cycle starting on 1st January, Li concentration of 6 ppm and UO_2-IO-22 months management) is also in line with operational practice as it allows for sufficient headroom to account for contingencies and site management policy (requirement for around 20% headroom). These values cover the two most likely combustion modes currently considered for the EPR. However, it cannot be ruled out that another combustion mode may be envisaged in the future, and the liquid tritium discharge authorisation may have to be reviewed. This is not currently the case.

Overall, it is thus expected that the EPR maximum annual discharge of liquid tritium would be a combination of the annual performance without contingency and the added contingencies as described. Hence, the maximum discharge during normal operation, estimated at 75 TBq/y, should account for any contingency met during the operation of the plant, such as start-up, shutdown (planned or unplanned), site management policy decisions (equilibrium between tritium produced and discharged not attained), etc and covers the two combustion modes potentially envisaged for the EPR. Normalised to 1000 MW, this value represents a 35% decrease over the annual limit for liquid tritium discharges at Sizewell B (67.23 TBq/y at Sizewell B vs. 43.23 TBq/y for the EPR).

6.2.2.3. Analysis of Operating Experience Feedback, factors influencing the liquid tritium discharges and proposed values for monthly discharges

Appendix A-3 and Appendix A-4 give the monthly profiles and rolling monthly profiles of the liquid tritium discharges for the Flamanville and Paluel sites over the periods 2002-2007, both as total and as percentages of the annual site discharge limits. From these graphs, it can be seen that the monthly discharges of liquid tritium over the years considered are variable and range between 1% and 21% of the total annual site discharge limit at Flamanville, and between 2% and 15% of the total annual site discharge limit at Paluel.

The determination of monthly discharge values is very difficult due to the nature of the tritium discharges, being very dependent on the operating conditions, as seen above, and the site management policy. As such, values recorded at Flamanville (two-unit site) show that the monthly liquid tritium discharges can vary between less than 1 TBq/month and over 12 TBq/month, representing up to 20% of the current annual site discharge limit (15% of the discharge limit submitted in the discharge authorisation renewal). Similar records at Paluel (four-unit site) represent up to 14.5% of the annual site discharge limit. Overall, the fluctuations over the whole fuel cycle are significant. Other sites (such as Penly) have shown that monthly discharges can reach up to 25% of the annual discharge limit for one unit.

As seen before for the annual discharges, the management policy used at each site can play a major role in the monthly discharges of liquid tritium as well as annual. Although tritium production is closely linked to the production of energy, and the fleet management policy is to discharge all tritium produced, the liquid discharges do not necessarily follow the production profile. Indeed, internal management of the liquid effluent can lead a site to discharge more tritium at a given time of the year or of the fuel cycle (e.g. at start-up), and the management of liquid effluent may prevent discharges from being carried out according to the initial plan. As such, some sites have chosen in the past to reduce the tritium activity of the primary circuit as far as possible and therefore the TEP [CSTS] distillates have been transferred to the "T tanks" (0KER [LRMDS]). This implied that part of the tritium contained in the circuits was also transferred to the "T tanks" and discharged. This management method is used on a regular basis on existing sites in order to comply with the radiochemical objective of the primary circuit, and in particular is used prior to reactor shutdown in order to reduce the tritium activity of the primary circuit.

On the other hand, it can be decided to temporally reduce the discharges as much as possible, and in this case effort is not focussed on reducing the activity of the primary circuit but on recycling the TEP [CSTS] distillates. This means that tritium is concentrated in the circuits instead of being discharged. This management technique can only be used temporarily as it is generally advised to limit the tritium activity in the primary circuit. However, this method can be used if, for a particular reason, the discharges need to be reduced (for example, in the case of a non-coastal site, if the river flow rate does not allow tanks to be emptied). Similarly, the "deconcentration" of the primary circuit (to reduce the tritium activity of the primary circuit) will temporarily increase the tritium liquid discharges.

Due to the nature and the management policy adopted for the liquid discharges (use of storage tanks), it is possible that up to two months production of liquid tritium is discharged in one month. Considering a worst case scenario where this maximum discharge of two months production coincides with the maximum tritium production of the cycle, it was estimated that this would correspond to around 25% of the annual discharge released in a month. This leads to a maximum monthly discharge of 18.75 TBq/month. In the absence of contingencies, the monthly discharges are expected to be around 25% of the annual expected performance, i.e. 13 TBq/month. The associated headroom is expected to cover for all contingencies considered above, whether linked to operational events or uncertainties due to the lack of OEF.

6.2.3. Influence of the current proposed annual limit on the radiological impact

As mentioned previously, the current proposed annual limit for the discharge of liquid tritium from an EPR unit is 75 TBq/y. It is generally considered that the total dose constraint for the most exposed member of the public from liquid discharges (i.e. a fishing family where adults spend 2000 hours a year fishing near the coast and children and infants spend 300 hours and 30 hours a year, respectively, playing on the coast) from annual discharges is 300 $\mu Sv.y^{-1}$, and that the associated threshold for optimisation is 20 $\mu Sv.y^{-1}$.

Although the proposed annual maximum discharge value for liquid tritium can be considered to be significant, it is generally reported that the overall impact of these discharges on the dose received by members of the public is relatively low.

In the situation considered (annual discharge of 75 TBq/y for liquid tritium), the most exposed members of the public would receive a dose associated to the discharges of liquid tritium of 1.8×10^{-2} $\mu Sv.y^{-1}$, 4.9×10^{-3} $\mu Sv.y^{-1}$ and 1.7×10^{-3} $\mu Sv.y^{-1}$, respectively, when considering an adult, a child and an infant (see Chapter 11 of the PCER).

The greatest dose from liquid tritium discharges would thus be received by an adult. Even so, the dose received from liquid tritium would only represent a fraction of the dose constraint (less than 0.01%) and of the threshold for optimisation (0.09%). In addition, the contribution of liquid tritium discharges on the total dose received by the most exposed member of the public from liquid discharges would not be significant, representing only about 0.10% of the total dose received by adults, children and infants respectively.

As such, even though the proposed maximum discharge value for liquid tritium can be seen to be high due to the headroom applied to the expected performance estimate, the discharges would only have a minor radiological impact on the overall dose received by the most exposed members of the public.

6.3. LIQUID DISCHARGES OF CARBON-14

6.3.1. Production

C-14 is a radioisotope with a long half-life (5730 years); it is a low-energy pure beta emitter (E_{max} = 156 keV) which is produced in the primary coolant of a PWR mainly from the following reactions:

- O-17 (n, α) -> C-14;
- N-14 (n, p) -> C-14;
- C-13 (n, γ) -> C-14.

The main sources are the neutron activation of O-17 which is an isotope of the oxygen contained in the water coolant and N-14 (depending on the concentration of dissolved nitrogen in the primary coolant). Carbon-14 production from carbon activation is very low compared to that formed by oxygen and nitrogen, even with zinc injection. The production of carbon-14 due to the zinc injection as zinc acetate ($Zn(O_2CCH_3)_2(H_2O)$) is negligible [Ref-1] [Ref-2]. Carbon-14 is also formed in large quantities in the fuel from oxygen and the UO_2 and nitrogen impurities, but remains contained in the sealed cladding. Moreover, the behaviour of C-14 produced from the oxygen and nitrogen contained in solid phase in the cladding material is not known. As a result, these formation methods, which mainly concern the downstream cycle, will be ignored.

The “aeroball” neutron flux monitoring system may also be a source of C-14, as the beads used to measure flux are driven by nitrogen.

Finally, the neutron reactions in the nitrogen and oxygen in the reactor pit may lead to the formation of C-14.

6.3.1.1. Carbon-14 formation rate from the primary coolant

The neutron flux used for EPR calculations is derived from Operational Technical Specifications and based on a 99-group flux for a 1300 MW(e) PWR core (UO_2 4.95% close to UO_2 EPR IO 18-month management) and an average core burn-up of 40 GWd/tU. As regards 1300 MW(e) calculations, the flux used is a 99-group flux for the GEMMES fuel management scheme and a burn-up of 30 GWd/tU.

For one metric ton of water under flux, the calculated production is:

- from the oxygen in the water (H_2O): 6.17 x 10^7 Bq/Equivalent Full Power Day (EFPD) for the EPR and 6.36 x 10^7 Bq/EFPD for the 1300 MW(e) PWRs;

- from the dissolved nitrogen in the primary coolant: 6.69 x 10^5 Bq/EFPD.ppm for the EPR and 7.27 x 10^5 Bq/EFPD.ppm for the 1300 MW(e) PWRs;

- from the carbon present in the primary coolant: 11.2 Bq/EFPD.ppm for the EPR and 14.1 Bq/EFPD.ppm for the 1300 MW(e) PWRs.

C-14 production from the carbon is very low compared to that formed from the oxygen and the nitrogen. As a result, this last method of formation is discounted.

Given the reaction rates of these transformations, the main source of C-14 is the reaction with the oxygen in the primary coolant water. This method of formation is inevitable in PWRs.

Due to the difference in technology between the EPR core and that of a 1300 MW(e) PWR, the production of C-14 per unit of mass is lower for the EPR than for a 1300 MW(e) PWR. However, as the EPR reactor is more powerful and the expected availability is higher, its “absolute” C-14 production will be higher than for a 1300 MW(e) PWR.

6.3.1.2. Incidence of dissolved nitrogen in the primary coolant

The production of C-14 is also sensitive to the concentration of dissolved nitrogen in the primary coolant which depends on the design of the connected systems and their mode of operation.

The dissolved nitrogen concentration for 1300 MW(e) PWRs is of the order of 0.1 to 1ppm. This nitrogen comes mainly from the air impurities via the water and boron make-up, but also from the hydrazine injected during start-up, to remove the residual dissolved oxygen. The injection of about 30 litres of hydrated hydrazine into the primary system at the start of the cycle corresponds to the production of a residual nitrogen concentration of about 0.1ppm. In addition, nitrogen from the air in tanks is reduced in 1300 MW(e) facilities due to the presence of a floating cover on the REA [RBWMS] water tanks.

On the EPR, the nitrogen enters from the water and boron make-up tanks and the RCV [CVCS] tank in which the cover gas is purged with nitrogen from the TEG [GWPS].

Fluids which may contain nitrogen from the RCV [CVCS] tank to the RCP [RCS] enter from several sources:

- a 10% flow from the blowdown used to maintain a boron concentration in the tank close to that of the RCP [RCS]. The continuation of this flow is to be confirmed;

- a zero flow line between the outlet of the RCV [CVCS] pumps and the RCV [CVCS] tank;

- the injection return at primary pump seals to the RCV [CVCS] tank.

The water and boron tanks are flushed with slightly depressurised nitrogen (0.8 bar g). Make-up from these tanks to the RCP [RCS] will be significant, particularly during load follow operation.

The input of nitrogen to the primary system is thus related to the make-up from the water and boron tanks and permanent circulation of the primary coolant in the RCV [CVCS] tank.

The nitrogen concentration in the primary coolant inherent in the use of the EPR RCV [CVCS] can be evaluated conservatively, assuming that the concentration is that of the tanks and reservoirs connected to the primary system.

In tanks with a cover gas, there is equilibrium between the gases over the reservoir and the dissolved gases in the liquid, according to Henry's Law which gives the concentration of gases dissolved in a liquid in equilibrium.

$$P_i = kC_i$$

where: Pi: partial pressure of the gas i in the gaseous phase above the liquid;

Ci: concentration of gas i in the liquid;

k: Henry's constant, for nitrogen above water at 45°C, k=0.08476 kg.bar/Ncm^3.

Assuming that the partial nitrogen pressure above the RCV [CVCS] tank is 1.8 bar abs and the temperature of the liquid in the RCV [CVCS] tank is 45°C (conditions of the Konvoi RCV [CVCS]), the mass fraction of nitrogen in the fluid, governed by Henry's law, is then 27 ppm approximately. That of the water and boron tanks is about 12 ppm, as the pressure of the nitrogen cover gas is 0.8 bar g.

6.3.1.3. Estimate of Carbon-14 production in the primary coolant

The table below gives the annual production of C-14 for the EPR as a function of the concentration of dissolved nitrogen in the primary coolant. The production coefficient considered for the EPR is 91%. (Number of EFPD in the year / 365, which conservatively is taken as equal to the availability):

Nitrogen concentration (ppm)	Annual production of C-14 (Kd (availability coefficient) = 91%) GBq/year
0.1	401
1	405
10	**444**
12[1]	*453*
27[2]	*518*

Table 14: Estimate of the C-14 production depending on N_2 concentration in the primary coolant

This contribution to the source term does not affect the decision to use nitrogen as a cover gas in the RCV [CVCS] tank, given the reduction in the risk of a hydrogen explosion which led to this decision.

Overall, it was estimated that, considering a reasonable operating nitrogen concentration of 10ppm in the RCP [RCS], the annual production of C-14 would reach 444 GBq/y (calculated from the source term), equivalent to 34 Bq/kWh for an availability coefficient (Kd) of 91%. By comparison, for the existing 1300 MW(e) reactors, a similar value of 34 Bq/kWh is reached with a much lower availability coefficient (Kd = 85%), and is equivalent to an annual production of 327 GBq/y.

[1] Concentration of dissolved nitrogen in the makeup water and boron tanks.
[2] Concentration of dissolved nitrogen in the RCV tank.

It is however possible that the nitrogen concentration in the RCP [RCS] will be higher than 10 ppm (up to 27 ppm, or potentially even higher), and therefore annual production of C-14 may be higher than 444 GBq/y. It was estimated that for a nitrogen concentration of 27 ppm, the C-14 annual production would be 518 GBq/y, equivalent to 40 Bq/kWh. A scenario involving a maximum concentration of 52 ppm in the primary circuit was also considered, resulting in an annual C-14 production of 620 GBq/y. In all cases, the C-14 activity susceptible of being produced by zinc acetate injection only represents about 1×10^{-4} to 3×10^{-4}% of the C-14 coming from the other sources. Therefore, the potential C-14 produced by zinc acetate may be considered as negligible [Ref-1].

6.3.2. Liquid discharges of C-14

6.3.2.1. Estimate of C-14 expected performance and maximum discharge value

The majority of C-14 is degassed during the treatment of the primary effluent in the TEP [CSTS] and directed to the gaseous effluent treatment system to be discharged as gaseous effluent. Some of the C-14 contained in the primary effluent may be retained on filters and resins before reaching the TEP [CSTS], although there are no specific industrial treatments such as filtration for the treatment of C-14 in PWRs. The C-14 from the non-recyclable effluent may also be retained on filters, resins and in the concentrates from the treatment of the effluent by evaporation. A summary of the production and treatment system for liquid C-14 in the EPR is given in Figure 10.

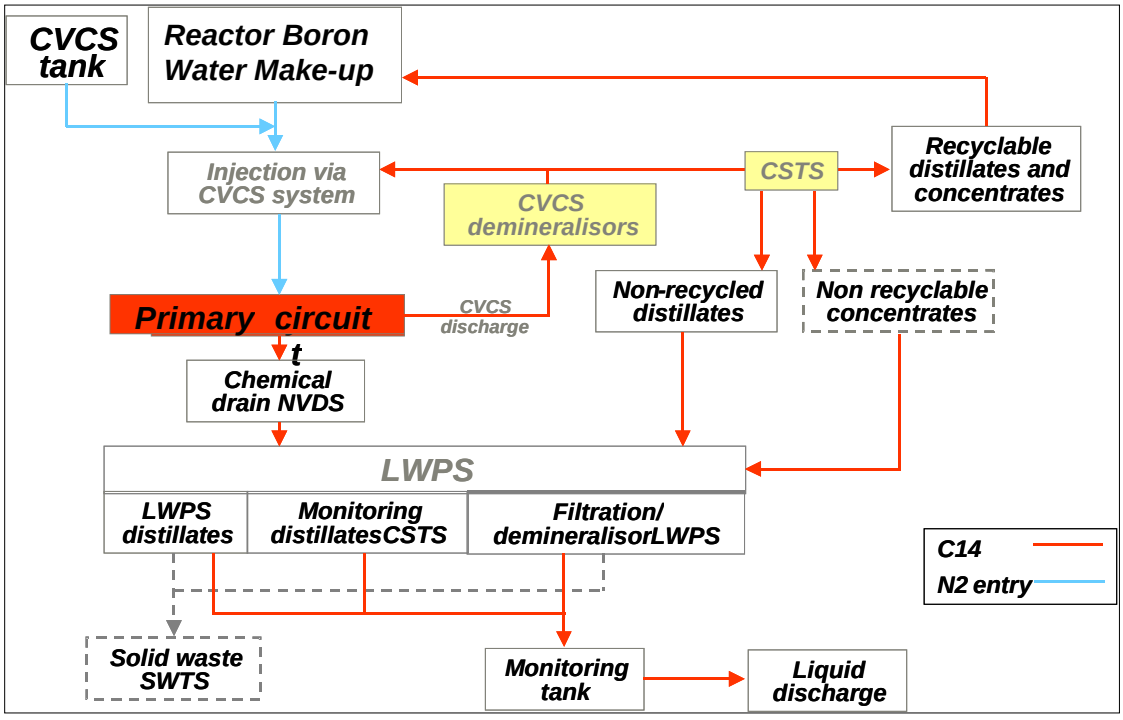

Figure 10: EPR production and discharge of liquid C-14.

Thus, although the C-14 produced must be discharged either as solid, liquid or gaseous effluent, it is estimated that only a small proportion of the C-14 initially in liquid phase is discharged in liquid effluent. However, there are major uncertainties regarding both the concentration of nitrogen in the primary circuit (see section 6.3.1.3) and the distribution between liquid, solid and gaseous discharges, and in particular between solid and liquid waste. Indeed, it is generally assumed that 80% to 95% of the carbon-14 produced in PWRs is released in gaseous effluents with the remaining 5% to 20% in liquid and solid waste. These uncertainties are associated with the chemical form of carbon-14, which is a determining factor of carbon-14 behaviour in the plant processes.

Operating experience feedback on the 1300 MW(e) facilities between 2001 and 2003 shows calculated average annual discharges from 15.5 to 16.2 GBq, i.e. 1.76 Bq/kWh. The few values measured (short-term feedback) are of the order of 11 to 12 GBq and confirm the ratio used to calculate the estimate reasonably well (15 GBq/GWyr).

The current estimated discharge of liquid C-14 (expected performance excluding contingency) is evaluated by extrapolating from this feedback based on the Kd (availability coefficient) of 91%, at **23 GBq/year.** This is very similar to the value calculated assuming that 4% of the source term (518 GBq/y, 27 ppm nitrogen) is discharged in liquid effluent, and is expected to be the lowest annual discharge (expected performance).

As regards to the maximum discharge value, the following factors were taken into account:

- for the EPR no specific techniques are available to improve C-14 management, and
- a positive effect expected from increased recycling of effluent (see following paragraphs) is an increase in the passage of the C-14 from liquid to gas, and
- a negative effect expected from using nitrogen as a cover gas in the RCV [CVCS].

From the lack of operating experience feedback available for the EPR, the uncertainties of the split of C-14 between liquid and gaseous phase, the higher nitrogen concentration involved and the increase in power production, the maximum C-14 liquid discharges could be expected to be higher than that of the 1300 MW(e) reactors. However, it was estimated that the increased recycling of the effluents, associated with a higher proportion of C-14 discharged in gaseous effluent will counterbalance the negative effects stated above, and therefore it is expected that the annual maximum discharges of liquid C-14 will be similar to that of the 1300 MW(e) reactors, i.e. 95 GBq/y.

NB: It should be noted that the current annual discharge limits for Flamanville and Paluel are 400 GBq/y and 800 GBq/y, respectively. However, the discharge authorisation request submitted to the French regulators for Flamanville 1 and 2, requested that a new (lower) annual limit be set for both 1300 MW(e) units on site, at 190 GBq/y. This would be equivalent to 95 GBq/y C-14 discharge in liquid effluent per unit. This value was based on a ratio of C-14 discharged in gaseous/ liquid effluent of 80/20.

This value of 95 GBq/y is thus the proposed annual maximum discharge value for one EPR unit, and integrates the uncertainty margin associated with the split of C-14 in the different phases. In addition, this maximum value includes the margin necessary to account for a nitrogen concentration in the RCP [RCS] above 10 ppm, which would lead to the overall production of C-14 being higher than the assumed 444 GBq/y.

6.3.2.2. Analysis of Operating Experience Feedback and factors influencing the annual liquid C-14 discharges

The current annual discharge limits for liquid C-14 for 1300 MW(e) sites are as follows:

- 400 GBq/y for Flamanville site (2-unit site);
- 800 GBq/y for Paluel site (4-unit site).

However (see above), the value was reviewed in the most recent authorisation request for water intake and liquid and gaseous releases for the Flamanville site (submitted in 2006), and decreased to 190 GBq/y.

Appendix A-5 and Appendix A-6 show the calculated annual discharges of C-14 liquid for the Flamanville and Paluel sites respectively between 2002 and 2007, both as total activity discharged and as percentages of the annual site discharge limit.

Over the course of the period studied, the highest discharge reported was around 40 GBq/y at Flamanville, and around 65 GBq/y at Paluel. These values constitute less than 10% of the current annual discharge limits for each site (or 20% of the discharge limit requested in the new authorisation for Flamanville).

However, it is important to emphasise the fact that the values reported are calculated values as opposed to measured ones. The calculation is based on a ratio linked to the electrical production of the plant of 15 GBq/GWe per year. Discrepancies occur when comparing the calculated and the measured data, in particular due to the complexity of carbon-14 behaviour through the different processes of the plant, depending on its chemical form. This is illustrated in Appendix A-7 where both the calculated and measured liquid C-14 discharges at various French nuclear power plants have been presented for 3 of the years of the period considered (2004, 2005 and 2006). From these figures, it is evident that there are large discrepancies between the two methods of assessment, and although the calculated estimates are usually much higher than the measured values, there are a number of cases (especially at Flamanville) where the opposite has been observed.

These considerations provide evidence that the accurate prediction of discharges for C-14 is difficult. The close relationship between the production of C-14 and that of power, associated with the higher source term production due to the higher concentration of nitrogen implies that the use of OEF to determine the expected performance and maximum discharges is not necessarily considered as the best option. In addition, the large uncertainties associated with this method require large headroom between expected performance and maximum discharge, which will potentially be reviewed once sufficient OEF is available.

6.3.2.3. Analysis of Operating Experience Feedback, factors influencing the liquid C-14 discharges and proposed values for monthly discharges

The calculated monthly discharges of liquid C-14 for Flamanville and Paluel over the period 2002-2007 are given in Appendix A-8 and Appendix A-9. As mentioned previously, production of C-14 in a PWR is closely linked to the power produced in a reactor and therefore limiting the overall discharges of C-14 could be equivalent to limiting the power production of a reactor. Operating experience feedback from existing 1300 MW(e) reactors shows significant variations in the monthly discharge profiles. As the production is proportional to the power production, variations due to a number of minor contingencies are observed, similarly to what is observed for liquid tritium. Despite these contingencies, the overall source term for the production of C-14 is however generally well controlled.

Over the 5 years considered (2002-2007) at Flamanville and Paluel, the highest monthly discharge was lower than 3% of the annual site limit (just under 10 GBq/month at Flamanville and 12 GBq/month at Paluel). This maximum value also represents 5% of the new limit as in the discharge authorisation renewal (190 GBq/y instead of 400 GBq/y).

As was the case for the annual discharge values, these results need to be considered carefully as they are predicted rather than measured values. In the light of this, it is very difficult to provide estimates for monthly discharges depending on a number of operational scenarios such as start-up, shutdown, maintenance operations, etc, and to provide estimates of the headroom required to account for operational situations.

Generally speaking, it can be assumed that there are no major operating contingencies that could significantly impact the production of C-14 in an EPR reactor, but this does not necessarily imply that variations of the C-14 liquid discharges cannot be observed due to the site management policy for the liquid effluents.

Overall, because the production of both C-14 and tritium is very dependent on the power produced, it is expected that the average and monthly discharges of liquid C-14 will represent the same percentage of the annual C-14 liquid discharge as that of liquid tritium is to the annual liquid tritium discharge (see section 6.2.2.2).

In such a situation, a maximum monthly discharge of liquid C-14 of 24 GBq/month (25% of the annual maximum discharge) seems to be a reasonable estimate, prior to this value being reviewed in the light of measured values and operating experience feedback. This value would account for normal operating conditions such as start-up, shutdown (planned or not) along with a number of contingencies or maintenance operations, which have been estimated to potentially contribute up to 19 GBq/month.

6.3.3. Influence of the current proposed limit on the radiological impact

As mentioned previously, the current proposed annual limit for the liquid discharges of carbon-14 from an EPR unit is 95 GBq/y. It is generally considered that the total dose constraint for the most exposed member of the public from liquid discharges (i.e. a fishing family where adults spend 2000 hours a year fishing near the coast and children and infants spend 300 hours and 30 hours a year, respectively, playing on the coast) from annual discharges is 300 $\mu Sv.y^{-1}$, and that the associated threshold for optimisation is 20 $\mu Sv.y^{-1}$.

Carbon-14 is known for having a large influence on the total dose received from liquid or gaseous discharges, and, although the annual discharge limit is much lower than for that of tritium, its radiological impact is expected to be much higher.

In the situation considered (annual discharge of 95 GBq/y for liquid C-14), the most exposed members of the public would receive a dose associated to the discharges of liquid C-14 of 14 $\mu Sv.y^{-1}$, 4.2 $\mu Sv.y^{-1}$ and 1.4 $\mu Sv.y^{-1}$ when considering an adult, a child and an infant respectively (see Chapter 11 of the PCER). The greatest dose from liquid C-14 discharges would thus be received by adults, and C-14 discharges would be the main contributor to the total dose received by the most exposed members of the public from liquid discharges, representing 82%, 89% and 93% of the total dose received by infants, children and adults respectively. Even so, the dose would represent less than 5% of the dose constraint, and the contribution of C-14 to the total dose received from liquid discharges would be below the 20 $\mu Sv.y^{-1}$ threshold for optimisation.

Thus, although headroom was added to the expected performance to determine the annual limits, the dose that would be received from the annual discharge limit of liquid C-14 would only be a fraction of the dose constraint for the most exposed members of the public. In addition, this limit may be reviewed in the light of operating experience feedback data, once available. Indeed, as seen above, it has been observed for other plants (1300 MW(e) reactors) that the annual calculated discharges were less than 10% of the annual site discharge limit, in which case the actual dose received from C-14 liquid discharges would be much lower than the optimisation threshold. However, due to uncertainties and discrepancies between the calculated and the measured data, and the fact that no operating experience feedback data is currently available for the EPR, it is suggested that the current proposed discharge limit for the EPR maximum discharge of 95 GBq/y should remain.

6.4. LIQUID DISCHARGES OF OTHER RADIONUCLIDES

Operating experience feedback from existing reactors has shown that 30% of the radioactive discharge is related to process drains, 1% to chemical effluent, 60% to floor drains and 9% to laundry effluent and 8TEU [LWPS] distillates [Ref-1]. The performance expected from the EPR due to its design is:

- process drains: recycling of the primary liquid effluent aerated in the TEP [CSTS] generates a reduction of around 35% for this type of effluent (or 10% in total) due to the TEG [GWPS] compatibility with aerated gaseous effluent, particularly during unit shutdown;

- floor drainage: the design, incorporating improved selective collection, greater differentiation of floor drainage, means that only floor drains 1 (FD1) and 2 (FD2) are treated by the 8TEU [LWPS] (by filtration). In the event of pollution, the FD1 can be transferred to the chemical drain tanks of the 8TEU [LWPS] for treatment by evaporation via the RPE [NVDS] floor drain relay sumps; similarly, the FD2 can be transferred to the evaporator if necessary from the 8TEU [LWPS] floor drains. The floor drains 3 (FD3) are usually transferred to the 0SEK [SiteLWDS] as they are not contaminated. In the event of contamination following a fault, they can be transferred to the 8TEU [LWPS] floor for filtration prior to discharge. Hence, the design of the EPR means that it is possible to direct effluent to the various treatment lines of the 8TEU [LWPS] (filtration, demineralisation, evaporation) and there is the flexibility during treatment to choose between the production of liquid effluent or solid waste, and thus to best meet the technical, environmental and economic constraints. The benefit from this optimisation is difficult to quantify, all the more so, as the best current operating units have managed to update their procedures to direct the contents of the floor drain according to the activity. The EPR design incorporates the practices of the best current units, whilst simplifying operation.

Consequently, the EPR enables at least a 10% reduction in the activity discharged in liquid form (fission and activation products), excluding tritium and carbon-14, compared to the fleet's best 1300 MW(e) units [Ref-1].

6.4.1. Liquid Iodine Discharges

6.4.1.1. Production and discharge

Iodine isotopes are formed in the fuel by fission and can escape into the reactor coolant water via fuel defects. Also, like other fission products, small quantities are produced from uranium contamination on surfaces within the reactor, which can also be found in the primary coolant.

As explained in Sub-chapter 5.5 of the PCSR, the majority of iodine isotopes are in ionic form in the liquid phase, and will therefore indirectly be treated on filters and demineralisers. Liquid iodine isotopes are normally largely retained in the RCV [CVCS] demineralisers. The treatment process of liquid iodine in the EPR is illustrated in Figure 11.

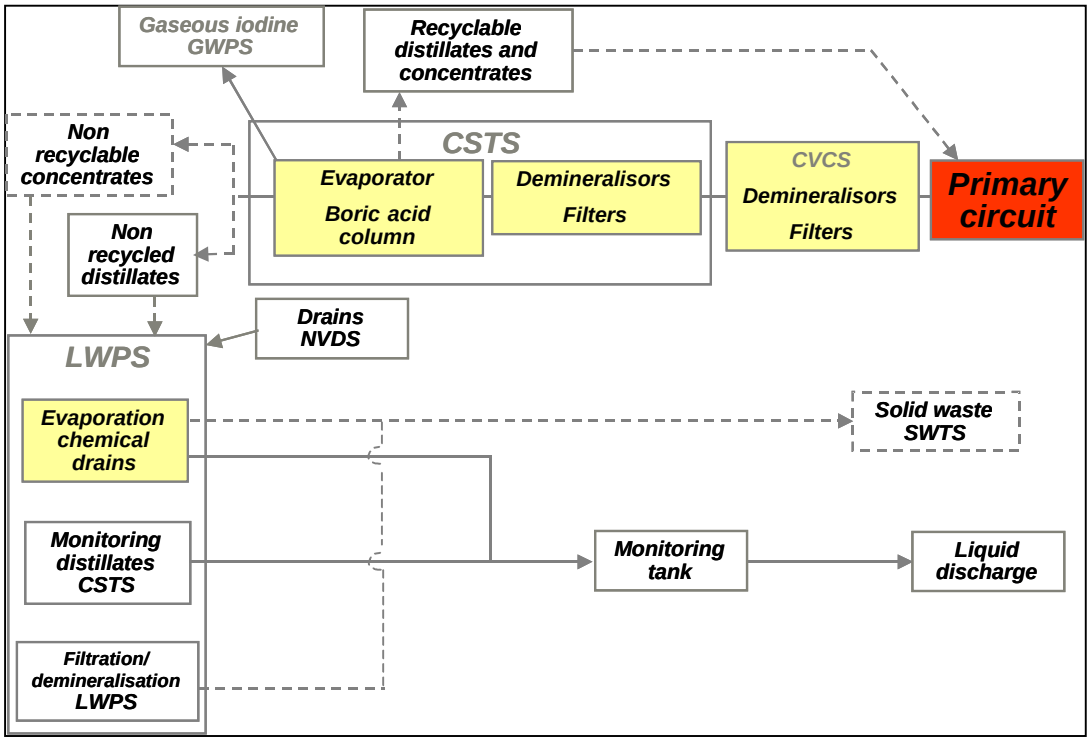

Figure 11: EPR liquid iodine treatment process

Iodine-131 is the longest lived radionuclide of this category, with a half-life of 8.04 days, and emits both beta and gamma radiations. It is not significant in discharges during normal operation, and, in the event of a major fuel failure at power in the EPR, the Nuclear Auxiliary Building, the Safeguard Building and the Fuel Building assemblies are able to put in service iodine adsorption beds on gas discharge outlets to trap it and reduce its gaseous discharges as much as possible.

Since they are well retained by the treatment systems and especially the RCV [CVCS] demineralisers, liquid iodine isotopes are never found in large quantities in liquid discharges. General iodine discharges usually happen at shutdown and start-up, which generates large volumes of gaseous effluent to be treated in the TEG [GWPS], and during maintenance operations requiring the opening of the system transporting the primary fluid, in which they can pass via defects in the fuel clad. The lack of leak tightness of the circuits can also be a source of release of iodine isotopes, for example in the case of leaking valves or sumps. Escape and discharge of iodine isotopes through defects is accentuated by changes in reactor conditions, particularly reactor power and pressure that occur during operations such as reactor shutdown. This reaction is known as fission product spiking. Leaking fuel pins are located during refuelling and not reused. If there were any major fuel failure at power, actinides would be released into the reactor cooling water.

Operating experience feedback based on the first quartile of the entire fleet of 1300 MW(e) reactors in France has shown liquid iodine discharges of around 0.7 mBq/kWh, equivalent to 7 MBq/y (considering a reference annual production from 1300 MW(e) reactors of 9800 GWh). This very low value is equivalent to a sum of detection thresholds, and considering the specificities of the EPR, is used as the EPR annual expected performance. The EPR maximum annual discharge for liquid iodine is estimated at 50 MBq/y (see section 6.4.1.3).

6.4.1.2. Analysis of Operating Experience Feedback and factors influencing the liquid iodine discharges

6.4.1.2.1. Annual discharges

The current annual discharge limits for liquid iodine for 1300 MW(e) sites are as follows:

- 100 MBq/y for Flamanville site (2-unit site);
- 100 MBq/y for Nogent site (2-unit site);
- 100 MBq/y for Saint Alban site (2-unit site);
- 200 MBq/y for Paluel site (4-unit site).

Appendix A-10 to Appendix A-13 show the annual discharges of I-131 liquid for the Flamanville, Paluel, Nogent and St Alban sites, respectively, between 2002 and 2007, as total activity discharged and percentages of the annual site discharge limit. The discharges shown on the graphs are generally low at these sites.

Annual discharges below 18 MBq/y are usually observed at Flamanville (2 units), below 25 MBq/y at Nogent and St Alban (2 units each), and around or below 40 MBq/y at Paluel (4 units), except in 2002 where values of up to 40 MBq/y and 130 MBq/y were observed at Nogent and Paluel respectively. Operating experience feedback based on the first quartile of the entire fleet of 1300 MW(e) reactors in France has shown liquid iodine discharges around 0.7 mBq/kWh. On the whole, these values are still very low and are close to the limits of detection of the instruments used. No major design improvements in the EPR are likely to significantly affect the discharges of liquid iodine compared to that of the 1300 MW(e) reactors, especially due to the fact that most values recorded result from a sum of limits of detection (in the absence of contingency).

Higher values are however expected due to potential contingencies. Major contingencies have been identified as being related to fuel leaks and faults in treatment systems, which are likely to significantly impact the iodine liquid discharges. However, it is not expected that the occurrence of a single contingency would greatly affect the discharge. Indeed, it is evident from the OEF that the liquid discharges of iodine are usually low and account for a sum of detection threshold values, rather than actual measured data. Although the concentration of liquid iodine can sometimes be high in the primary circuit, the confinement of the systems and the effluent treatment systems before discharge is usually very efficient at removing these radionuclides prior to discharge. As such, even in the event of a contingency (a fuel leak for example), it is not expected that high discharge values will be observed as the iodine would be retained before discharge. This is in particular the case observed for the higher values at Paluel and St Alban in 2002.

6.4.1.2.2. Monthly discharges

Appendix A-14 to Appendix A-17 show the monthly and rolling monthly discharges of I-131 liquid for the Flamanville, Paluel, Nogent and St Alban sites, respectively, between 2002 and 2007, as total activity discharged and percentages of the annual site discharge limit. These figures show some variations in the monthly I-131 liquid discharges over the period studied, and it is evident that the profile of these discharges over a whole fuel cycle is not flat. However, although it has been established that the I-131 discharges were higher during reactor shutdown and at start-up, this is not necessarily obviously shown on the figures. Indeed, since the only discharge data available were for the whole site, as opposed to for each unit, the effect of start-up and shutdown of one unit is not as obvious as if the data plotted were for a single unit. In addition, this is emphasised by the fact that the liquid effluents of both units are mixed together in the various tanks before discharge, and that discharge can be delayed with the effluent being held up before discharge. Despite this, at Flamanville, the highest monthly discharges of liquid I-131 seem to occur when at least one of the units is shutdown.

Generally speaking, the monthly discharges only represent a fraction of the annual site discharge limit for liquid iodine isotopes. Typically, most of the discharges are less than 5% of the annual site limit, and the rolling monthly discharges are usually around 20% of the annual site discharge limit. As explained before, these values are very low, and it can be considered that they are the result of a sum of detection or threshold limits, rather than a real illustration of the I-131 content of the liquid discharges. As such, it is estimated that these low values overestimate the actual I-131 activity of the effluent discharged, and that monthly or yearly variations are not necessarily meaningful.

However, on a number of occasions, the monthly discharges recorded were noticeably higher. At Nogent, the highest monthly discharge is equivalent to 26.2% of the annual site discharge limit; at Paluel, equivalent to 22.7%; and at St Alban equivalent to 14.1%. These high values provide evidence of operational contingencies significantly affecting the composition of the liquid discharges. It has been established that if, for example, there were a major fuel failure at power, significant amounts of iodine isotopes would be released into the cooling water. Although the treatment systems can retain most of the activity due to iodine isotopes in liquid effluent, the situations experienced at Paluel, Nogent and St Alban provide justification for the need for large headroom between the EPR expected performances without contingency and the annual maximum discharge (see section 6.4.1.3) to cover any contingency due to a combination of fuel leaks and failure of one or more treatment systems. In particular, the situation encountered at these sites proves that a large part of the annual activity can be discharged in one month. This was the case at Nogent when the liquid iodine discharges in December 2002 reached 26.2 MBq, representing 65% of the total 2002 site activity (40.6 MBq/y) discharged as liquid iodine, or, to a lesser extent at St Alban, when 14.1 MBq was released in November 2002, representing 56% of the total 2002 activity (24.9 MBq/y) discharged as liquid iodine.

6.4.1.3. Liquid iodine quantitative targets

It has been established above that the discharges of liquid iodine under normal operating conditions are equivalent to a sum of detection thresholds. Based on OEF from the first quartile of the entire fleet of 1300 MW(e) reactors, the expected performance for the discharges of liquid iodine from the EPR was estimated at 7 MBq/y. High discharges over a short period of time can however occur due to contingencies, and significantly affect the discharges. Because the "baseline" discharges (under normal operating conditions) are so low, the impact of contingencies is very large, and therefore headroom between expected performance and site maximum discharge value is required in such an event. In this case, the liquid iodine discharges would be much higher than during normal operation without contingency. Although difficult to quantify, contingencies are expected to contribute for more than 40 MBq/y if an event happens (see Paluel and Nogent in particular), and therefore an annual maximum discharge of 50 MBq/y for liquid iodine isotopes would provide a minimum margin. In addition, when compared to some of the other limits, this value is only marginal, and presents a 25% improvement of the EPR when compared to the 1300 MW(e) reactors per energy unit produced.

Under normal operating conditions, the expected performance for monthly discharges would be equivalent to a sum of detection thresholds, and equivalent to 0.7 MBq/month. However, it was established that high discharges would be very limited in time and would therefore impact monthly discharges more than annual discharges (in comparison to normal operating conditions, see Nogent 2002). Therefore, in a worst case scenario (involving fuel leak, unavailability of the treatment systems and the unavailability of one of the final storage tanks), it is not impossible to assume that the contingency could contribute up to 90% of the headroom provided on the annual estimates, and a maximum monthly value of 50 MBq/month could potentially be discharged.

6.4.1.4. Influence of the current proposed limit on the radiological impact

As mentioned previously, the current proposed annual limit for the liquid discharges of iodine from an EPR unit is 50 MBq/y. It is generally considered that the total dose constraint for the most exposed member of the public (i.e. a fishing family where adults spend 2000 hours a year fishing near the coast and children and infants spend 300 hours and 30 hours a year respectively playing on the coast) from annual liquid discharges is 300 $\mu Sv.y^{-1}$, and that the associated threshold for optimisation is 20 $\mu Sv.y^{-1}$.

The radiological impact of iodine isotopes has been studied in the past, and it is generally agreed that the main pathway leading to possible radiation dose to people is by deposition of I-131, which is consumed by cows and then transferred to humans by the consumption of milk. Thus, the liquid discharges of iodine are generally only considered to have a minor radiological impact.

In the situation considered (annual discharge of 50 MBq/y for liquid iodine), the most exposed members of the public would receive a dose associated to the discharges of liquid iodine of 7.6×10^{-5} $\mu Sv.y^{-1}$, 3.8×10^{-5} $\mu Sv.y^{-1}$ and 2.2×10^{-5} $\mu Sv.y^{-1}$ respectively when considering an adult, a child and an infant (see Chapter 11 of the PCER).

The greatest dose from liquid iodine discharges would thus be received by adults, but, even so, the dose would represent less than 10^{-4}% of the dose constraint and less than 0.001% of the threshold for optimisation. The contribution of liquid iodine to the total dose received by the most exposed member of the public is thus a fraction of the total dose received (17 $\mu Sv.y^{-1}$ for an adult), and considered as not significant. As such, the discharges of liquid iodine would only have a minor radiological impact on the overall dose received by the most exposed members of the public.

6.4.2. Other liquid discharges of fission and activation products

6.4.2.1. Production and discharge

The “other fission and activation products” category includes a number of radionuclides routinely measured in liquid effluents, in particular: Mn-54, Co-58, Co-60, Ag-110m, Te-123m, Sb-124, Sb-125, Cs-134, Cs-137, Ni-63. Some additional radionuclides may only be periodically detected, such as Cr-51 or Nb-95. The injection of zinc as depleted zinc ensures that low activities of Zn-65 are maintained [Ref-1].

The typical distribution of the overall activity discharged between the different radionuclides in the group “other fission or activation products” was determined using the average discharges from currently operating 1300 MW(e) units, over the period 2002-2004 (see Table 15). No operating experience feedback data is available for the EPR unit; the 1300 MW(e) category has been chosen as the reference, since information about it is readily available, and its design is, overall, similar to that of the EPR.

Radionuclide	Percentage of FP/AP activity discharged
Ag-110m	5.7
Co-58	20.7
Co-60	30
Cs-134	5.6
Cs-137	9.45
Mn-54	2.7
Sb-124	4.9
Sb-125	8.15
Ni-63	9.6
Te-123m	2.6
Others[3]	0.6

Table 15: Distribution of fission and activation products in radionuclides discharged in liquid form.

Fission products are usually present in the reactor cooling water. Indeed, despite a high standard of cleanliness, a trace of uranium always remains on the fuel surfaces after the manufacturing process. Once the fuel is in the reactor, this “tramp” uranium will fission, producing fission products in the reactor cooling water. Another route for other radionuclides to enter the reactor coolant system is as a result of fuel leaks.

The presence of activation products (AP) is due to the activation of elements present or passing through the reactor core and thus subject to neutron flux.

The most significant radionuclides of this category are usually considered to be: Cs-134, Cs-137 (fission products), and Co-58 and Co-60 (activation products).

[3] “Others” correspond to all of the various radionuclides that may be episodically detected. For a 1300 MWe plant in France, the "others" category is represented by Cr-51.

- **Caesium-134 and 137:**

  Both Cs-134 and Cs-137 are beta and gamma emitters. Cs-134 is not a direct fission product but is created in the fuel by the activation of Cs-133 (which is a fission product). As explained in Sub-chapter 5.5 of the PCSR, the caesium isotopes are not used for fuel failure detection but for estimation of burn-up [Ref-1]. They have similar chemical behaviour, whether inside the power station or when released in the environment, and are routinely minor constituents of liquids for processing. The demineraliser resins can usually remove most of them. Their concentration in the primary circuit usually increases during the shutdown operations, in particular in the presence of fuel leaks.

- **Cobalt-58 and 60:**

  As explained in Sub-chapter 5.5 both Co-58 and Co-60 are beta and gamma emitters. They are produced by neutron activation and constitute some of the corrosion products found in a nuclear reactor. Co-58 comes from Ni-58, a major constituent of the steam generator tubes and of the stainless steel in core and vessel materials. Co-60 is produced from neutron activation of reactor steel components, particularly the hard-wearing alloy stellite (although use of the hard-wearing alloy stellite is avoided as much as possible and these alloys are replaced whenever possible to reduce the activation of Co-59 to Co-60 [Ref-2] [Ref-3], see Chapter 8 of the PCER).

  Although the reactor coolant chemistry is carefully controlled in order to avoid corrosion, it is unavoidable that some steel activation products are released into the coolant. Thus, both isotopes are usually seen in the reactor coolant system water, and can be a problem if there are leaks and when components are opened up for maintenance. Both are major radioactive constituents of liquid processed prior to disposal.

Because they are closely associated with the fuel, fission products appear in the primary circuit if the fuel is leaking. The production of corrosion and fission products peaks during reactor shutdown (especially due to the oxygenation of the RCP [RCS] for corrosion products and due to the change in temperature and pressure for the fission products) and they constitute a real hazard when maintenance requires opening of pipework or components. The fission products in the systems are mainly in soluble form while the corrosion products are partly in particulate form, and the latter particulates may be deposited on surfaces [Ref-2]. In addition, activation products also present a hazard due to the deposition of cobalt isotopes on all internal surfaces of the reactor coolant system.

Most of these “other radionuclides” can be removed efficiently by the processing of liquid waste that is performed. In particular, ionic or particulate forms of fission and activation products are usually retained on the filters and demineralisers of the various treatment systems (RCV [CVCS], TEP [CSTS], PTR [FPPS] or 8TEU [LWPS]) [Ref-3]. However, they still remain detectable in liquid effluent before discharge (see Figure 12).

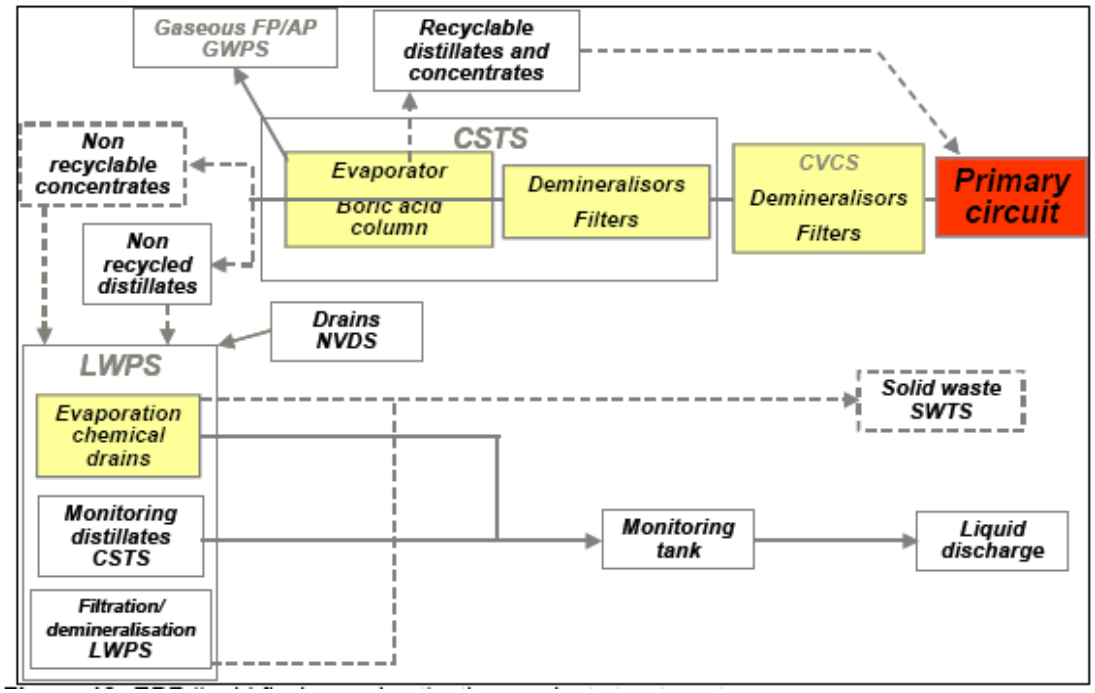

Figure 12: EPR liquid fission and activation products treatment process

According to operating experience feedback data, 30% of these fission/activation products result from process drains, 1% from chemical drains, 9% from the laundry and TEP [CSTS] distillates, and 60% from floor drains.

Discharge of the fission and activation products in liquid effluent does not necessarily exactly match their production due to potential delays and storage of the effluent to be discharged in tanks on site. In normal operating conditions (i.e. without leaking fuel), the discharges of fission and activation products are expected to be very low. However, their production and discharge will be significantly affected in the event of leaking fuel, and the associated activity to be discharged will be high due to the specific activities of these elements. As such, it is anticipated that significant margins are required between the expected performances without contingency and the annual limits, in order to account for the impact of the contingencies on the activity discharged.

Overall, considering that the discharges of fission and activation products are not directly linked to the energy produced, and taking into account the design improvements of the EPR compared to the 1300 MW(e) reactors, especially on the treatment of the chemical, floor and process drains, it is expected that a 10% reduction of the activity discharged from liquid radionuclides other than C-14, H-3 and I-131 will be achieved compared to the existing reactors. This is reflected in the EPR expected performance without contingency (0.6 GBq/y) and the annual maximum discharge of 10 GBq/y.

6.4.2.2. Analysis of Operating Experience Feedback and factors influencing discharges of the liquid fission and activation products

6.4.2.2.1. Annual discharges

The current annual discharge limits for liquid fission and activation products for 1300 MW(e) sites are as follows:

- 25 GBq/y for Flamanville site (2-unit site);

- 25 GBq/y for St Alban site (2-unit site);
- 50 GBq/y for Paluel site (4-unit site).

Appendix A-18, Appendix A-19 and Appendix A-20 give the annual discharges of liquid fission and activation products for the Flamanville, Paluel and St Alban sites, respectively, over the period 2002-2007, as total activity discharged and percentages of the annual site discharge limits.

Over the course of the 5 years studied, the annual liquid discharges in this category of radionuclides were always less than 25% of the annual site discharge limit, and mostly under 10% of the limit at Flamanville and Paluel. Thus, applying such a large margin between the operating experience feedback and the annual maximum discharge value of the EPR can seem unreasonable. However, due to the high dependence on fuel behaviour, the contingencies attached to it, and the important contribution of such contingencies to liquid discharges of fission and activation products, imposing a high limit in comparison to the discharges in normal operation is not unreasonable. Indeed, in the event of fuel leaks and reactor shutdown associated with failure of the treatment systems, the liquid discharges could be much higher over a short period of time. This was the case at St Alban power station where an evaporator was unavailable for a number of months in 2004 and 2005 which forced the site to discharge the effluent without any treatment other than decay in the final storage tanks. No major fuel leaks were encountered at the time which meant that the overall annual liquid discharges of fission and activation products remained reasonably low (although higher than that at Flamanville and Paluel), as the site was able to cope by managing its effluents differently and storing the liquid effluent in the final storage tanks before discharge. However, the variations over the course of the year show the change in management of the effluent.

Additional contingency involving an accidental contamination of the primary fluid, followed by discharge without decay which could potentially lead to high levels of activity released, also needs to be considered. For example, due to the high specific activity of these elements, accidental contamination of a relatively small volume (60 m^3) of effluent with Co-60 at Penly led to the unplanned release of around 13 GBq of activity into one of the final storage tanks. In order to avoid the discharge of any high levels of activity in the environment, it was decided that the effluent should be kept into the final storage tank for a sufficient period of time for the activity to decay (i.e. until 2009). Although this decision impacted on the availability of all the storage capacity on site (one less tank available), it enables most of the activity to decay before discharge.

Thus, reasonable headroom taking account of these potential contingencies (pollution of the effluent with high specific activity elements and failure of the treatment/monitoring systems before discharge) is required in order to assess a realistic value of the maximum annual discharge.

6.4.2.2.2. Monthly discharges

Appendix A-21, Appendix A-22 and Appendix A-23 give the monthly profiles and rolling monthly profiles of the liquid fission and activation products discharges for the Flamanville, Paluel and St Alban sites over the periods 2002-2007, as total activity discharged and percentages of the annual site discharge limits. It can be seen that the monthly liquid discharges for this category of radionuclides are usually very low at all sites, typically around or less than 1% of the annual site limit, essentially representing a sum of detection thresholds. However, on a number of occasions, and due to contingencies, the discharges reached a higher level, although never more than 5%.

The behaviour of the monthly profile and the associated low discharges at both Flamanville and Paluel over the period studied are not surprising. Indeed, as mentioned above, in normal conditions (i.e. with no fuel leaks), the liquid discharges of radionuclides other than C-14, H-3 and I-131 are not expected to be significant. In the period studied, no fuel leaks were reported at either site and therefore high discharges were not expected to be seen (sum of detection thresholds rather than actual activity discharged).

However, the situation at St Alban reported above (unavailability of an evaporator in 2004 and 2005) impacted the monthly discharges over a number of months over that period. In particular, it can be seen in Appendix A-23 that discharges of up to 870 MBq/month and 1320 MBq/month (in May 2004 and November 2004 respectively) were reached over the period, in the absence of any other contingency. These higher discharges represented 38.5% and 49.7% respectively of the total activity discharged over the course of 12 rolling months (2250 MBq discharged between June 2003 and May 2004, and 2650 MBq discharged between November 2004 and October 2005). This gives strong evidence that the monthly profiles for the discharges of liquid fission and activation products are highly influenced by operating conditions, and that sufficient headroom is required between expected performance and maximum discharges. In particular, it can be expected that a similar situation to that of St Alban (failure of a treatment system) associated with fuel leaks could lead to monthly discharges much higher than 50% of the overall discharge over 12 months.

In addition, there is a large variation in the monthly discharge with the point of the fuel cycle considered. Indeed, although the correlation between production and discharge of liquid effluent is not necessarily easy to make, it is evident that discharges following shutdown are much higher than during operation. This is especially the case when the shutdown period is short. In the absence of any contingency, it was reported at Penly that discharges following a planned shutdown were around 6 times higher than during operation. In the presence of contingency, this phenomenon is expected to be even more pronounced as the activity in the primary fluid will be even higher. In addition, the shorter the shutdown, the higher these discharges are expected to be. Considering that the EPR refuelling activities are expected to last for around 11 days (much shorter than for existing reactors), and considering the OEF above, it can be envisaged that the totality of the annual maximum discharge could be released in this shutdown period (less than a month).

6.4.2.3. Liquid fission and activation products quantitative targets

The expected performance without contingency for the liquid discharges of other fission and activation products is estimated to be 0.6 GBq/y. This value is considered to be very low and, in particular, is due to the relatively short half-lives of these elements which enable them to be kept for sufficient time to decay before discharge in normal operating conditions without contingency. This value was estimated using the operating experience feedback of the first quartile of the best 1300 MW(e) reactors, considering a discharge per unit of energy produced of 61 mBq/kWh for the existing reactors [Ref-1]. However, it has been established that contingencies could account for much higher discharges. In particular, a combination of a failure of one or more of the treatment systems together with the unavailability of a discharge tank could lead to activity levels around 10 GBq/y (see section 6.4.2.2.1).

In the light of these considerations, an EPR annual discharge limit for liquid fission and activation products of 10 GBq/y seems reasonable.

Monthly discharges of these radionuclides are very difficult to predict, as they are very dependent on the effluent management policy adopted on site, the point of the fuel cycle considered and the contingencies encountered. As reported above, monthly discharges during shutdown but under normal operating conditions are typically 6 times higher than during operating phases. This would lead to a monthly expected performance of 0.3 GBq/month (annual expected performance without contingency normalised per month without any shutdown period multiplied by 6). In the presence of contingencies, it was noted previously (see section 6.4.2.2.2) that a maximum monthly discharge equal to the annual maximum discharge (10 GBq) could be envisaged, and would involve a combination of normal operating conditions and contingencies, i.e. short shutdown, fuel leak, fault of a treatment system and unavailability of a final storage tank preventing natural decay from occurring before discharge.

6.4.2.4. Influence of the current proposed limit on the radiological impact

As mentioned previously, the current proposed annual limit for the liquid discharges of radionuclides other than C-14, H-3 and I-131 from an EPR unit is 10 GBq/y. It is generally considered that the total dose constraint for the most exposed member of the public (i.e. a fishing family where adults spend 2000 hours a year fishing near the coast and children and infants spend 300 hours and 30 hours a year respectively playing on the coast) from annual liquid discharges is 300 $\mu Sv.y^{-1}$, and that the associated threshold for optimisation is 20 $\mu Sv.y^{-1}$.

All of Cs-134, Cs-137, Co-60 and, to a smaller extent Co-58 (less soluble than the other radionuclides considered) can, when discharged in the sea, accumulate in living organisms (such as fish) and in sediments and silts. The principal pathway for radiation dose to the public is through the ingestion of local fish and shellfish, and possibly by occupation of inter-tidal areas where there may be silt deposits. Cs-137, having a longer half-life than Cs-134 (30.07years vs. 2.06 years) will give a higher dose to the public for a similar activity discharged, whereas Co-60 (5.27years half-life) is one of the most significant radionuclides in the “other radionuclides” group. Co-58 has the shortest half-life of all (71 days) and is relatively insoluble, but its contribution to doses to members of the public is often significant. In addition, it constitutes a significant part of the solid radwaste due to its accumulation on spent ion exchange resins and filters from the processing of liquid effluent.

An annual discharge of 10 GBq (proposed annual limit for EPR) of liquid radionuclides including Mn-54, Co-58, Co-60, Ag-110m, Te-123m, Sb-124, Sb-125, Cs-134, Cs-137, Ni-63, and Cr-51 (according to a standard spectrum) would lead to an annual dose to the most exposed member of the public of 3.27 $\mu Sv.y^{-1}$ for adults, and 0.53 $\mu Sv.y^{-1}$ and 0.06 $\mu Sv.y^{-1}$, respectively, for children and infants (see Chapter 11 of the PCER). The largest part of the dose received by each age group is attributable to Co-60.

In these conditions, the greatest dose from discharges of these radionuclides would thus be received by an adult, but, even so, the dose would only represent about 1.1% of the dose constraint and just over 16% of the threshold for optimisation. This category of radionuclides would be the second largest contributor to the dose from liquid discharges, after C-14, due to the dose received from Co-60 (3.1 $\mu Sv.y^{-1}$ for Co-60 alone for an adult). It would represent almost 20% of the total dose received by an adult from liquid discharges (17 $\mu Sv.y^{-1}$), 11% of the total dose received by a child from liquid discharges (4.7 $\mu Sv.y^{-1}$) or 3.6% of the total dose received by an infant from liquid discharges (1.5 $\mu Sv.y^{-1}$).

6.5. LIQUID DISCHARGES – CONCLUSIONS

As demonstrated above, establishing a predictive monthly profile for liquid radioactive discharges for the EPR is a difficult task. The lack of operating experience feedback, along with the dependent nature of operating conditions and contingencies for some of the discharges, makes the monthly discharges difficult to predict accurately for a set of given conditions. A summary table of the proposed monthly and annual values for the EPR is given in Appendix B-1.

In addition, although the production of liquid effluent is relatively well understood over a fuel cycle and for different operating conditions, production and discharge are not necessarily closely related in time. Indeed, operational conditions, along with site management strategies, mean that, in a number of cases, it is preferable to delay the discharges and keep the effluent on site for a period of time, whether in the discharge tanks or in the system itself (in the case of tritium in the primary circuit, for example). As such, the prediction of accurate monthly discharge values proves very difficult.

However, a number of generic operating conditions affecting the overall liquid discharges have been listed, including:

- management of effluent is largely site-dependent:
    - each site needs to adapt to its own conditions, such as the availability of the tanks (0KER [LRMDS], etc…). For instance, the liquid effluent management will be affected if one of the KER [LRMDS] tanks on site is unavailable, and there will be issues with storage and discharge.
    - meteorological conditions can have a large influence on both the discharge and the monthly profiles of the discharges. For example, a non-coastal site will not be able to discharge effluent unless the flow rate of the nearby river is between a minimum and maximum value. Outside of this range, the liquid discharge will need to be stopped and delayed, and thus the liquid effluent stored on site.
- the production of some of the liquid effluent (C-14, H-3) is almost a direct function of the power produced. However, as seen above, discharges can be delayed or held up for different reasons. In addition, the operating experience feedback is difficult to interpret due to the absence of unit-specific data for the liquid discharges. This is related to the fact that, for a multiple-unit site, the storage tanks are shared between the different units and therefore the correlation between start-up and shutdown, and other operating conditions of one unit and its liquid discharges, is ambiguous.
- the production of other radionuclides present in the liquid effluent is very dependent on the operating conditions of a unit and the associated contingencies. This is particularly the case for the fission and activation products and the iodine isotopes, whose concentration in the liquid effluent is generally low under normal operating conditions, but can massively increase in the case of leaking fuel for example. In addition, the production profile of such elements is not flat as they are released primarily during unit shutdown and therefore discharges are minimal while the unit is operating, but increase after shutdown. For these radionuclides, large headroom between the EPR expected best performances and the annual maximum discharges needs to be applied, as production is so significantly affected by contingencies.

Tritium:

As mentioned above, tritium production is almost directly linked to power production, although specific conditions of the primary circuit (in particular the boron content) can influence its production. It is possible to control the discharges of liquid tritium to a certain extent by changing operating conditions, for example, it can be concentrated in the primary circuit if discharges are required to be decreased over a period of time. However, it is generally advised that discharges should match production as much as possible.

As such, production and discharge are relatively predictable over a whole cycle, and it can be expected that the highest monthly discharges will happen at the beginning of a cycle, when the boron concentration of the primary circuit is at its highest. Minimal margin is applied between the EPR expected performance and the annual maximum discharges (52 and 75 TBq/y, respectively), and, normalised to 1000 MW(e), this maximum value represents about 65% of the Sizewell B annual site discharge limit. Additionally, an EPR maximum monthly discharge of 18.75 TBq (25% of the annual site limit) seems reasonable in light of the 1300 MW(e) operating experience feedback data. Potential contingencies are thought to account for up to 5.75 TBq/month. In addition, the contribution of liquid tritium discharges to the dose received by the most exposed member of the public is low compared to the overall dose received.

Carbon-14:

As for tritium, C-14 production is closely linked to the power production. The C-14 liquid discharge only represents a small part of the total C-14 discharge, and it is estimated that most C-14 is released as gaseous effluent. However, the exact proportion discharged in liquid and solid waste is not well understood. In addition, there are still uncertainties concerning the nitrogen concentration of the primary circuit, and therefore the overall C-14 annual production was determined using a number of scenarios with various nitrogen concentrations in the primary circuit.

Since its production is linked to the power produced, the monthly production of C-14 can vary between a few hundred MBq (at unit shutdown) and several tens of GBq, but the source term is relatively well controlled. However, measured operational data are not available and only calculated data have been used for the determination of the EPR expected performance and annual maximum discharges.

No obvious contingencies have been determined that could massively influence the C-14 liquid discharges from the EPR, and both the expected performance and annual maximum discharge values (23 GBq/y and 95 GBq/y, respectively) have been calculated taking into account different proportions of C-14 in liquid phase (5% and 20% of C-14 in liquid phase, respectively). In addition, with the limit currently proposed, C-14 constitutes the main contributor to the total dose received by the most exposed member of the public from liquid discharges (total dose 17 $\mu Sv.y^{-1}$, contribution of C-14 to this dose: 14 $\mu Sv.y^{-1}$). However, this is below the optimisation threshold. Since its production is closely linked to the power production, as it is for tritium, it is estimated that the monthly discharges of C-14 will follow that of liquid tritium. As such, as a first approximation, it is estimated that a maximum monthly discharge of 23.75 GBq/month (25% of the annual maximum discharge value) could be released in a month.

Iodine isotopes and other radionuclides:

Both these radionuclides categories are significantly affected by operating contingencies and fuel leaks in particular. In normal operating conditions, production and discharges are expected to be very low. However, in the event of fuel leaks, their production increases sharply. The discharges occur particularly at unit shutdown, and therefore the monthly profile can show a large variation over the course of a fuel cycle.

The expected discharges of liquid iodine are much lower than those of the other radionuclides, with the proposed EPR annual limit values of 50 MBq/y and 10 GBq/y respectively.

The operating experience feedback from 1300 MW(e) reactors gave very low discharges for both categories, with monthly discharges mainly being below 1% of the annual site limit. The cumulative values over a year were rarely higher than 10% of the annual site limit. However, knowing the influence of contingencies (fuel leaks and faults of treatment systems) on the discharges of these radionuclides, reducing the headroom between expected performance (7 MBq/y for iodine isotopes, 0.6 GBq/y for other radionuclides) and the proposed annual limits (50 MBq/y for iodine isotopes, 10 GBq/y for other radionuclides) would not provide sufficient margin for operation. Comparison of these values to Sizewell B values is difficult as the Sizewell B discharge authorisation only considers two categories other than tritium (Cs-137 and 'other radionuclides'). However, normalised to 1000 MW(e), the EPR maximum expected discharge values for other beta or gamma radionuclides only represent about 5% of those of Sizewell B.

Similarly, it is very difficult to provide a typical monthly discharge value as it is highly dependent on the scenario. However, OEF has provided evidence that large monthly variations can be encountered and that some monthly discharges account for most of the total fission and activation product activity discharged over the rolling 12 months of the period considered. Therefore, it is not unreasonable to imagine that a combination of fuel leaks and other contingencies such as faults in the treatment systems and unavailability of the delay tanks could lead to a monthly discharge of the same order of magnitude as the maximum annual discharge. In other words, 100% of the annual maximum discharge could potentially be released in a month for these radionuclides, i.e. 10 GBq/month.

7. GASEOUS RADIOACTIVE EFFLUENT DISCHARGES

7.1. EURATOM RECOMMENDATION AND FRENCH PRACTICE

The EURATOM recommendation 2004/2/Euratom [Ref-1] recommends that the discharge activity of all the following radionuclides should be assessed for gaseous discharges from nuclear power reactors:

- tritium*;
- carbon 14;
- noble gases: Ar-41, Kr-85*, Kr-85m, Kr-87, Kr-88, Kr-89, Xe-131m, Xe-133*, Xe-133m, Xe-135, Xe-135m, Xe-137, Xe-138;
- iodine isotopes: I-131*, I-132, I-133 and I-135;
- particulates (excluding iodine isotopes): Cr-51, Mn-54, Co-58, Fe-59, Co-60*, Zn-65, Sr-89, Sr-90*, Zr-95, Nb-95, Ag-110m, Sb-122, Sb-124, Sb-125, Cs-134, Cs-137*, Ba-140, La-140, Ce-141, Ce-144, Pu-238, Pu-239 + Pu-240*, Am-241*, Cm-242, Cm-243, Cm-244 ;.
- S-35* (for gas-cooled-type reactors only).

If nuclide-specific information on alpha-emitters is not available, then total alpha activity should be reported. In addition, similarly to liquid discharges, the recommendation states that "Member States should report the following information on radioactive discharges to the Commission (…):

- annual discharge values for each radionuclide listed above for which there is at least one measurement outcome above the decision threshold in the period considered, or for which at least a calculated assessment has been made in the same period;
- for each key nuclide (marked with a * in the above list), the highest value of the detection limit that has been obtained among all the measurements for the period considered;
- estimates of radionuclide discharges based on calculation, as a substitute for measurement, when measurement is not technically feasible (…)".

The practice currently implemented in France, and in line with the above Euratom Recommendation, is to report the gaseous discharges from nuclear power stations in 5 categories:

- tritium;
- carbon-14;
- noble gases;
- iodine isotopes; and
- other fission and activation products (including routinely at least Co-58, Co-60, Cs-134, Cs-137).

As French regulations do not allow any man-made alpha activity to be discharged from nuclear power stations, a measurement is carried out before discharge to ensure the absence of such products. Thus, according to EURATOM regulations, the measurements of alpha-emitting radionuclides are not reported as they are consistently below the decision threshold. Finally, according to the last point stated above, the C-14 discharges are estimated based on calculations rather than routine measurement. Reporting of C-14 measured values has only recently started at some of the French power stations, and for these, only quarterly data, rather than monthly, are available.

Gaseous effluent falls into one of three categories, specifically:

- gaseous effluent from the primary circuit. This effluent comes from degassing in the Primary Effluent Treatment System (TEP [CSTS]), or from the degassing and head spaces in facilities containing primary coolant or primary effluent;
- gaseous effluent from ventilation. This effluent is produced by the extraction and ventilation of potentially contaminable buildings (such as the Nuclear Auxiliary Building, the Fuel Building, the Safeguard Buildings, the Reactor Building, the Operational Service Centre, the Access Building and the Effluent Treatment Building) and is treated on filters and potentially iodine traps before discharge;

- gaseous effluent from the secondary circuit. This effluent is produced from small leaks occurring between the primary and the secondary systems, through which tritium leaks and appears in the secondary circuit and condensed secondary water. Some tritiated water can therefore appear in the main condenser off gas.

More details are given in Sub-chapter 6.2.

7.2. GASEOUS DISCHARGES OF TRITIUM

7.2.1. Production and discharge

The production of the tritium source term in a reactor has been described in section 6.2 and therefore will not be studied in detail here. Indeed, both liquid and gaseous tritium are produced from the same reactions, specifically:

- neutron activation of boron-10 in the primary coolant;
- neutron activation of lithium-6 in the primary coolant;
- production in the secondary neutron source clusters.

Because of the way it is produced, most tritium resulting from the operation of a nuclear power plant is present in the liquid form. As such, the majority of tritium will be discharged in the liquid effluents.

Once formed, tritium is present in the various tanks and storage pools as tritiated water. The main source of gaseous tritium is thus provided by the evaporation of the pools containing tritiated water, in particular the IRWST pool (less the amount of tritium that recondenses on the cold parts of the EVR [CCVS]), as well as from evaporation from the pools in the Reactor and Fuel Buildings. In the current 1300 MW(e) reactors, there is intermediate flushing of the TEP [CSTS] tank that is the source of around 80% of the tritiated gaseous effluent in discharges from these plants. To minimise this source of tritium, the EPR uses the alternative N4 system for the collection and treatment of primary circuit coolant as this is let down from the circuit over the operating cycle. As a result, this source of tritium is minimised and, in the EPR, the bulk is the tritium in gases originating from evaporation of the fuel pools. In addition, in case of an accident, additional gaseous tritium can be discharged from the ventilation of the Safeguard Buildings (not considered here as this is not included in normal operating conditions). The production and discharge process of tritium is illustrated on Figure 13.

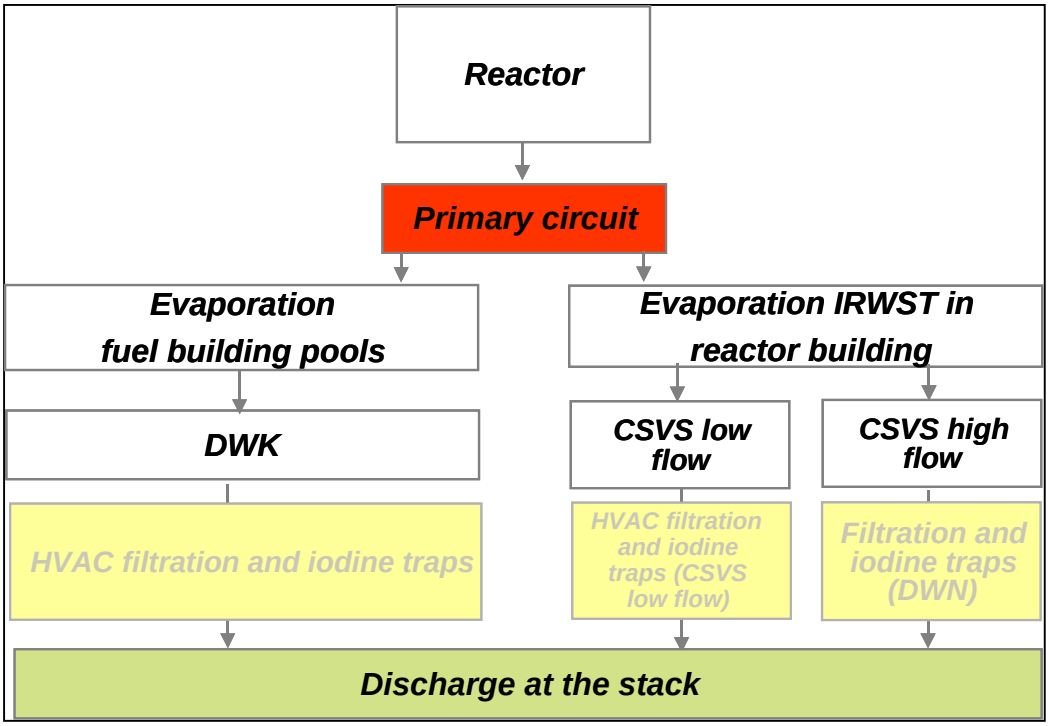

Figure 13: EPR gaseous tritium production and discharge process

As mentioned in section 6.2, the overall production of tritium is relatively well controlled and the source term well understood. However, because there are currently no efficient systems for its treatment before discharge, whether gaseous or liquid, the totality of tritium produced is discharged at some point as liquid or gaseous effluent. The proportion of tritium discharged in the gaseous form is thus difficult to assess and quantify as it can be largely influenced by operating conditions and the evaporation rate of the pools.

Because of the way it is produced and discharged, the discharges of gaseous tritium are continuous.

The expected performance without contingency and the proposed annual maximum discharge value for the EPR gaseous tritium discharges are 0.5 TBq/y and 3 TBq/y, respectively, and have been estimated using operating experience feedback data from the 900 MW(e) and N4 fleet. Indeed, it has been established (see above) that, considering the EPR design, the main source of gaseous tritium discharges comes from the evaporation of the storage pools (as for the 900 MW(e) and N4 reactors). The expected performance without contingency has therefore been calculated based on the ratio of the pool areas between the existing units and that planned for the EPR units, assuming a tritium concentration in the Fuel Building pool similar to that of the existing units. Considering that the source term is relatively well understood, it was decided that the lowest annual maximum discharge value for the existing units (3 TBq/y for N4 and 900 MW(e) reactors) should be applied for the EPR.

7.2.2. Analysis of Operating Experience Feedback and factors influencing gaseous tritium discharges

7.2.2.1. Annual discharges

The comparison of gaseous tritium discharges between the EPR and the 1300 MW(e) reactors is not meaningful due to design differences between the reactors. Indeed, by design and as explained above, there is no flushing of the intermediate TEP [CSTS] tank (unlike the 1300 MW(e) reactor, where most of the gaseous tritium discharge originates), hence most of the gaseous tritium discharge comes from evaporation from the fuel cooling pool (minus the quantity of water vapour recondensed on the cooling coils of the Reactor Building ventilation), as is the case in the 900 MW(e) and N4 plants. Comparison to 900 MW(e) or N4 reactors may thus be more meaningful. Operating experience feedback from both N4 sites (2 units each) was readily available, and therefore it was decided that these units would be considered for the following assessment, rather than the 900 MW(e) fleet.

The current annual discharge limit for gaseous tritium for both N4 sites (Chooz and Civaux) is 6 TBq/y, thus equivalent to a 3 TBq/y discharge limit per unit (2 units per site).

Operating experience feedback from these sites was studied over the period 2002-2007. The annual gaseous tritium discharges have only been given for the whole site as opposed to for each stack, and are represented in Appendix A-24 and Appendix A-25 respectively for Chooz and Civaux, respectively. Annual discharges of up to 1 TBq have been reported at Civaux, whereas the values are lower at Chooz, reaching up to 650 GBq/y.

Discharges of gaseous tritium are much more difficult to assess than those of liquid tritium. Indeed, although some of the main contingencies associated with the gaseous discharges of tritium are the same as those for liquid discharges and are associated with the source term (fuel management, management of the concentration of tritium in the primary circuit, overall energy production), other contingencies are more specific to the gaseous discharges themselves. In particular, this is associated with the conditions surrounding the pools, such as hygrometry, temperature, and other meteorological conditions that can affect the evaporation rates of the pools. The conditions are difficult to assess and their influence on the evaporation rates of the pools is currently being studied.

In addition, there are a number of indirect contingencies that may affect the conditions surrounding the pools and thus indirectly affect the evaporation rate and the production of gaseous tritium, such as loss of ventilation (partial or total). Indeed, in such a situation, the overall temperature and hygrometry of the buildings would be affected, in turn changing the conditions around the pool and potentially increasing the evaporation rate (due to an increase in the temperature of the building). Other indirect contingencies include potential incidental tritium pollution of the storage pools that, given the 12-year half-life of this element, would have a long term effect on the tritium levels present in the pools and would therefore affect several fuel cycles for the discharge of both liquid and gaseous tritium. These are considered to be the main contingencies affecting the gaseous discharges of tritium.

Moreover, it is expected that monitoring systems implemented in the EPR will provide more accurate measurement of the gaseous tritium activity discharged than those implemented on existing reactors. In particular, the refrigerated bubblers in place on the radiological protection measurement line are expected to trap a larger proportion of the gaseous tritium and therefore provide samples more representative of the actual discharge. As such, it is envisaged that the overall value recovered from monitoring of the gaseous effluent will give a higher content of gaseous tritium than that of existing units, but quantification of this improvement is difficult in absence of OEF. Similarly, design changes such as the management of the TEP [CSTS] are also difficult to quantify before any operational data are available.

Due to the current lack of operating experience feedback data to quantify the impact of the refrigeration of the bubblers on the overall tritium content reported, and of the other contingencies described above, it is essential that adequate headroom is applied to the EPR expected performance in order to provide sufficient margin for operational conditions and the maximum discharge value.

The highest annual discharge of gaseous tritium reported for the N4 sites is 1 TBq/y, and considering the lack of OEF to accurately quantify the impact of the EPR design changes and the difference between the power production for the N4 and EPR reactors, it is estimated that the 3 TBq/y maximum discharge expected for the EPR will provide sufficient headroom to cover all the contingencies encountered.

7.2.2.2. Monthly discharges

Appendix A-26 and Appendix A-27 give the monthly profiles and rolling monthly profiles of the gaseous tritium discharges for the Chooz and Civaux sites over the period 2002-2007, as total activity discharged and percentages of the annual site discharge limits. These data show that the most significant monthly discharges for gaseous tritium have been reached at Civaux, where monthly discharges of up to 135 GBq have been recorded. The highest values recorded at Chooz were around 90 GBq. Although these values represent less than 3% of the annual site discharge limits, the monthly profiles provide evidence that the discharges are not constant over a fuel cycle and that the greatest discharges are over 15 times higher than the lowest monthly discharges. In addition, it is useful to note that most of these maximum values were recorded when only one of the 2 units on site was operational, the other one being shutdown for maintenance. Thus, as a first approximation, it can be considered that these values are the maximum recorded over a month for one unit.

It was explained in an earlier section that tritium production is closely linked to the power produced, and therefore that the monthly gaseous discharge profile will closely follow the profile of the power production. As such, it is expected that the higher monthly discharges will represent only a fraction of the total annual discharge. This was the case both at Chooz and Civaux where the highest monthly discharges (both in June 2006) represented only a maximum of 1.5% and 2% of the total site discharge over 12 rolling months.

7.2.3. Gaseous tritium quantitative targets

The expected performance without contingency and the proposed annual maximum discharge value for the EPR gaseous tritium discharges are 0.5 TBq/y and 3 TBq/y, respectively. It has already been established that, considering the EPR design, the main source of gaseous tritium discharges are provided by evaporation of the storage pools. The expected performance without contingency was therefore calculated based on the ratio of the pool areas between the existing units and those planned for the EPR, assuming a tritium concentration in the Fuel Building pool similar to that of the existing units. Considering that the source term is relatively well understood, it was decided that the current minimum annual discharge limit for the existing units (3 TBq/y for N4 and 900 MW(e) reactors) should be used for the EPR maximum discharge value.

Reasonable headroom between the expected performance without contingency and the proposed annual maximum discharge value is required since, although the source term is relatively well understood, no operating experience feedback is currently available. As explained above, design changes have been implemented in the EPR that may affect the gaseous tritium discharges but are difficult to quantify, such as the management of the TEP [CSTS], the refrigerated bubblers in place for monitoring samples, or the impact of accidental pollution of the storage pools with liquid tritium, which would impact the discharges of tritium for several fuel cycles. Finally, this expected maximum discharge only represents 70% of the current Sizewell B limit normalised to 1000 MW(e) (1730 GBq for the EPR vs. 2520 GBq for Sizewell B).

Analysis of monthly data showed an almost linear relationship between production and discharge of gaseous tritium. As such, as explained above, the discharge profile is not expected to present any major fluctuations due to contingencies. Monthly variations of the discharges would be more likely to be linked to the power produced by the unit during the period considered, or conditions affecting the evaporation rate of the pools (such as temperature, hydrometry, etc). Overall, the impact of one month's worth of discharges on the total gaseous tritium activity discharged over 12 months is not expected to be significant, estimated at 10% of the total annual activity discharged. Therefore, reasonable estimates for the monthly discharge without contingency and maximum monthly discharges from gaseous tritium are evaluated at 50 GBq/month and 300 GBq/month, respectively (10% of the annual expected performance and of the annual maximum discharge, respectively). This is in line with the operating experience feedback, considering the increase in power produced by the EPR over the existing units, and would cover any normal operating conditions.

7.2.4. Influence of the current proposed limit on the radiological impact

As mentioned previously, the current proposed annual limit for the gaseous discharge of tritium from an EPR unit is 3 TBq/y. It is generally considered that the total dose constraint from gaseous discharges for the most exposed member of the public (i.e. a farming family living 0.5 km from the discharge point, where adults spend 50% of their time outdoors working on land adjacent to the site, and children and infants spend 20% and 10%, respectively, of their time outdoors) is 300 $\mu Sv.y^{-1}$, and that the associated threshold for optimisation is 20 $\mu Sv.y^{-1}$.

In the situation considered (annual discharge of 3 TBq/y for gaseous tritium), the most exposed member of the public would receive a dose of 1.4×10^{-1} $\mu Sv.y^{-1}$ for adults and children, and 2.6×10^{-1} $\mu Sv.y^{-1}$ for infants (see Chapter 11 of the PCER). The greatest dose from gaseous tritium discharges would thus be received by an infant, but, even so, the dose would represent less than 0.1% of the dose constraint or 1.3% of the associated threshold for optimisation. In addition, these values represent only a minor part of the total dose received by each age group, estimated at 4 $\mu Sv.y^{-1}$, 4.4 $\mu Sv.y^{-1}$ and 7.8 $\mu Sv.y^{-1}$, respectively, for adults, children and infants. In spite of this, tritium represents the second largest contributor to the dose received by the most exposed members of the public from gaseous discharges for an adult or a child, after gaseous carbon-14. Gaseous tritium represents the third largest contributor to the dose received by an infant from gaseous discharges, after carbon-14 and iodine-131.

Thus, although a margin has been added to the expected performance to determine the annual limits, the dose that would be received from the annual discharge limit of gaseous tritium would only represent a small part of the dose constraint and its associated threshold for optimisation for the most exposed members of the public. As such, even though the proposed maximum discharge values for gaseous tritium can be seen as high, the discharges would only have a minor radiological impact on the overall dose received by the most exposed members of the public.

7.3. GASEOUS DISCHARGES OF CARBON-14

7.3.1. Production and discharge

The discharges of carbon-14 comprise the liquid source term, which may occur by degassing, plus a specific gaseous source term. The liquid source term is described in section 6.3, and in Sub-chapter 6.1. The additional gaseous source term is linked to the operation of the "aeroball" system and to the atmosphere in the reactor pit.

7.3.1.1. Contribution of the "aeroball" system

The "aeroball" system, used to measure the neutron flux, includes 40 rods inserted in the assemblies. At the start of the measurement, beads containing vanadium are blown into these rods towards the core, by nitrogen. They are activated by the neutron flux and finally propelled by the nitrogen to a spectrometry system.

The gas from the bead transport is released into the Reactor Building after retention of the particles on a charcoal filter (see Figure 14).

The activity from the nitrogen consumed in one year is of the order of 9 MBq of C-14 (and 10 MBq of tritium) per unit [Ref-1].

In addition, if it is assumed that the nitrogen at atmospheric pressure remains confined in the aeroball rods between two flux scans and that the diameter of the EPR rods is the same as that of those at Konvoi (diameter 6 mm), the total annual activity produced is of the order of 1.5 GBq of C-14 (and 10 GBq of tritium) per unit [Ref-1].

Consequently, the "aeroball" system does not significantly contribute to the production of C-14 (and tritium) in the EPR.

7.3.1.2. Contribution of the reactor pit atmosphere

The activity of C-14 is estimated to be formed from the nitrogen and the oxygen in the reactor pit atmosphere based on the following assumptions:

- the neutron flux in the reactor pit is that of a 1300 MW(e) PWR;
- the active volume of the reactor pit is 29.11 m^3;
- the temperature is 35°C.

The activity thus obtained is 1 GBq/year for an EPR unit [Ref-1]. The contribution of the reactor pit atmosphere is thus negligible compared to that of primary coolant activity.

7.3.1.3. Contribution of the primary coolant

As mentioned earlier, carbon-14 is essentially produced from the activation of the oxygen-17 present in the water of the primary system. A smaller part is produced by activation of nitrogen-14 dissolved in the water of the primary system. The majority of C-14 degasses during the treatment of the primary effluent in the TEP [CSTS] and will be directed to the Primary Gaseous Effluent Treatment System (TEG [GWPS]) to be discharged as gaseous effluent, either in organic form (methane, ethane…) or mineral form (carbon dioxide). As such, gaseous discharges of C-14 are continuous and directly reflect the production of the reactor (when not shutdown). The production and discharge of gaseous C-14 is illustrated on Figure 14.

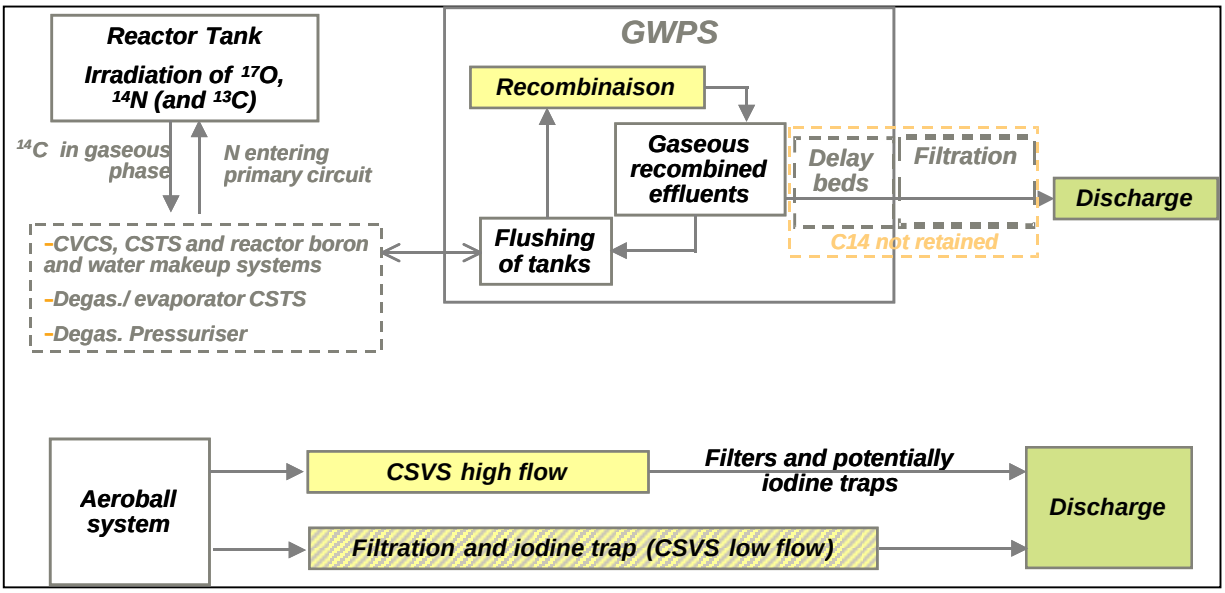

Figure 14: EPR production and discharge of gaseous C-14

It is estimated that the majority of the gaseous discharges are as methane (about 80%), and a smaller part is discharged as CO_2 (around 20%)[4]. In addition, due to the half-life of carbon-14 (5730 years), it is not possible to treat it in delay tanks and therefore all C-14 produced is discharged (either in liquid or gaseous form, with an estimated ratio around 80% to 95% gaseous and 5% to 20% as solid and liquid – see section 6.3).

Like the discharges of liquid C-14, a direct link exists between gaseous C-14 and power production, and therefore it is expected that gaseous C-14 discharges will increase proportionally to the power produced. During shutdown periods and as a result of the characteristics of the EPR, gaseous C-14 discharges are expected to be associated with the ventilation of the Reactor Building, and are considered to be low. It is however possible that, as for the 1300 MW(e) reactors, a peak will be observed for the C-14 discharges during shutdown due to the degassing of the pressuriser or primary circuit. No other major contingencies that could potentially affect the C-14 discharges have been identified. The lack of operating experience feedback does not allow this to be confirmed.

Considering the presence of a nitrogen atmosphere (rather than hydrogen) in the RCV [CVCS] tank, it was calculated based on the feedback from 1300 MW(e) units that, for the discharge of gaseous C-14, the source term associated with the nitrogen atmosphere of the RCV [CVCS] would produce 312 GBq/y of C-14. An additional term taking account of the nitrogen concentration in the primary circuit also needs to be taken into consideration (varying between 43 GBq and 117 GBq depending on the scenario considered, either 10 ppm or 27 ppm), and overall, the annual performance without contingency for EPR gaseous C-14 discharges based on a median scenario was estimated at 350 GBq/year. This estimate, equivalent to 27 Bq/kWh, presents a slightly higher value than the average of the 1300 MW(e) reactors (24 Bq/kWh), i.e. +12%, but is mitigated by the fact that the environmental impact of gaseous C-14 is much lower than that of liquid C-14 (see section 7.3.4).

[4] Dose calculations have however been based on a different split of gaseous C-14 (see Chapter 11 of the PCER).

The determination of the maximum annual discharge of gaseous C-14 was difficult due to the lack of operating experience feedback data and the limited number of measured data available for the 1300 MW(e) reactors, as opposed to calculated ones. Considering that the EPR does not present any major design improvements for the treatment and discharges of C-14, it was at first decided to base the determination of the EPR annual maximum discharge on the current 1300 MW(e) limit per unit of energy produced. This led to an annual maximum discharge value of 900 GBq/y. However, the analysis of the operating experience feedback from both 1300 MW(e) units and German KONVOI reactors, associated with calculations based on different values of the nitrogen concentration of the primary coolant (scenarios of 10 ppm, 27 ppm or up to 52 ppm in the primary coolant), and the uncertainties associated with the split of C-14 between the solid, liquid and gaseous phases led to a reassessment of this maximum value. The most conservative scenario considered (maximum concentration of nitrogen in the primary circuit of 52 ppm) would lead to an annual source term of 625 GBq/y for which the annual expected performance would reach up to 500 GBq/y. Estimations based on these assumptions, associated with the operating experience feedback data given below, lead to a more realistic value of 700 GBq/y as the maximum annual discharge for gaseous C-14. However, the initial estimate of 900 GBq/y was considered for the dose calculations (see Chapter 11 of the PCER).

7.3.2. Analysis of Operating Experience Feedback and factors influencing the gaseous C-14 discharges

7.3.2.1. Annual discharges

The EPR design significantly differs from the current 1300 MW(e) reactors in the fact that the RCV [CVCS] tank is under a nitrogen atmosphere as opposed to a hydrogen atmosphere. This is in place to reduce the hydrogen risk (reduction of the hydrogen storage by more than 1000 m^3), and has been adapted from the German KONVOI reactors. As such, an estimation and comparison of the EPR performance regarding discharges of carbon-14 to the existing 1300 MW(e) reactors is not necessarily meaningful, and it would be preferable to compare performance with operating experience feedback of the KONVOI reactors. Although only limited operating experience feedback data was available from the KONVOI reactors, the data available from Emsland (KKE), Neckarwestheim 2 (GKN-2) and ISAR 2 (KKI-2) will be analysed below. The data given below for the 1300 MW(e) reactors are thus given for information purposes.

The current annual discharge limits for gaseous C-14 for 1300 MW(e) sites are as follows:

- 1400 GBq/y for Flamanville site (2-unit site);
- 2800 GBq/y for Paluel site (4-unit site).

There are no single annual limits for gaseous C-14 discharges from the German KONVOI reactors. Instead, a limit on total noble gases, tritium and C-14 is in force. Activities as high as 1100 TBq/y are allowed to be discharged from ISAR 2 each year.

Only a few sites of the existing 1300 MW(e) French fleet currently measure C-14 discharges. For all of the other sites, the values reported are calculated quarterly using the power produced over a given period and the source term. As such, the values reported may not give an accurate representation of the actual discharge. Indeed, as shown in Appendix A-28, and similarly to the liquid discharges, large discrepancies can be observed between the calculated and the measured values of gaseous C-14 discharges.

Appendix A-29 and Appendix A-30 show the annual discharges of gaseous C-14 for the Flamanville and Paluel sites, respectively, between 2002 and 2007, both as total activity released and percentages of the annual site discharge limit. However, the annual data obtained for Paluel are to be considered carefully as some of the records were not available, and therefore only the first two quarters of each year are displayed on the graphs. Thus, the annual discharge data presented for Paluel are expected to be largely underestimated as only half of the year's discharges were considered, and these data will therefore be discarded. Appendix A-31 presents the annual discharges of gaseous C-14 for ISAR 2 as total activity discharged over the same period (2002-2007), and the similar data for the three KONVOI reactors over the periods 1995-2003. These later graphs are not given as a percentage of the annual site discharge limit as there is no single limit for C-14 discharges, but one for gaseous tritium, C-14 and noble gases altogether.

Analysis of the annual data at Flamanville shows discharges between 5.7 GBq/y and 288 GBq/y per unit. The cumulative values for both units range between 52 GBq/y and 366 GBq/y, presenting a large variability. Annual discharges from the KONVOI reactor considered (ISAR 2) over the same period are much higher, ranging from 260 GBq/y to 490 GBq/y. In addition, rolling data range from 120 GBq/y to just over 600 GBq/y.

Over a less recent period (1995-2003), the annual data gathered for the three KONVOI reactors are also very variable, ranging from 67 GBq/y (Neckarwestheim 2, 1995) to 700 GBq/y (Emsland, 1999, see Appendix A-31).

It is evident from the above operating experience feedback that the gaseous C-14 discharges are generally higher for the KONVOI reactors than those of the 1300 MW(e) reactors. This was expected due to the greater use of nitrogen in the KONVOI reactors, and the situation is expected to be similar in the EPR since the TEG [GWPS] was adapted from the KONVOI design. In addition, the gaseous C-14 annual discharges are very variable over the years considered for a single site, and large discrepancies between the KONVOI sites considered are also observed (ISAR 2 discharges are generally higher than that of Neckarwestheim 2), although no major contingencies have been identified to explain these variations.

Overall, these results emphasise the uncertainty that exists in the process and the requirement for sufficient margin to allow for normal operation of the reactor. In order to better understand the process and to allow for more accurate prediction of the C-14 discharges, a monitoring programme has recently been launched in France to collect measured data, rather than calculated, and provide sufficient OEF to assess discharges more accurately. Meanwhile, it is essential that enough margin is applied to the EPR maximum discharge value in order to allow for normal operation of the unit. Normalised to the EPR net power production (1630 MW(e)), the highest discharge value recorded for the KONVOI reactor (700 GBq/y in 1999 at Elmsland 1290 MW(e)) would be equivalent to 885 GBq/y. This is similar to the first estimate of the expected EPR maximum discharge value of 900 GBq/y. However, the calculations on the source term associated with the nitrogen concentration in the primary circuit and the more recent values reported for the KONVOI unit (maximum value reported at ISAR 2 of 490 GBq/y, equivalent to 620 GBq/y normalised to the EPR power production) justify the more realistic maximum discharge value of 700 GBq/y. This value is considered to provide sufficient margin to allow for the operation of the reactor prior to any OEF being available.

7.3.2.2. Quarterly discharges

The operating experience feedback data for all the individual stacks at Flamanville and Paluel have been collected over the years 2002-2007. However, monthly records are not available for gaseous C-14 discharges, as the samples of the discharges are only analysed every three months. Thus, the following analysis will be carried out on quarterly data given in Appendix A-32 and Appendix A-33. Similar data for ISAR 2 (KONVOI reactor) are given in Appendix A-34. The data for the other two KONVOI site were not available for this analysis.

Since C-14 production is roughly proportional to the power produced during operation, it is expected that the profile observed for the EPR will not be flat over a whole cycle due to the fluctuations in power production. In addition, the EPR profile is expected to be slightly different to that of the 1300 MW(e) reactors, since the TEG [GWPS] design changes have removed the need for planned discharges as exists in the current fleet of reactors. Indeed, a large part of the gaseous C-14 is discharged from the 1300 MW(e) reactors during shutdown operations, during degassing operations of the primary circuit. Although the pressuriser is continuously degassed in the EPR, there are uncertainties concerning the profile of discharges and the possibility of higher discharges at given times of the fuel cycle.

The profile of the gaseous C-14 discharges from the KONVOI reactor can however give an indication of the expected behaviour of the EPR. Although the profile of gaseous C-14 discharge is closely associated with the power produced, higher discharges may also be observed at reactor shutdown, during maintenance operations involving degassing of the primary circuit.

The operational discharge values given in Appendix A-32 to Appendix A-34 present significant fluctuations of the quarterly discharges of C-14, depending on the unit considered. Indeed, the highest quarterly discharge recorded at Flamanville reached 120 GBq (unit 2, 3rd quarter 2007), and the highest discharge recorded at Paluel reached 200 GBq/quarter (unit 3, first quarter 2003). Quarterly discharges from the ISAR 2 KONVOI reactor are also widely spread, ranging from 9 GBq/quarter (January – March 2004) to 340 GBq/quarter (July - September 2005). Values accumulated over 4 quarters (12 months) range from 120 GBq/12 months to 600 GBq over 12 month, and the highest value recorded in 2005 represents over 70% of the total activity released from gaseous C-14 discharges over the year considered (2005, highest quarterly discharge 340 GBq, annual discharge 450 GBq/y). No major contingencies were identified to explain the quarterly variations observed over the course of the period studied other than those linked to normal operation. As such, these fluctuations provide evidence that, although no major contingencies have been identified to potentially significantly affect C-14 gaseous discharges, one high discharge over a relatively short period of time can significantly impact the yearly release, and again justifies the need for adequate margin.

7.3.3. Gaseous C-14 quantitative targets

The expected performance without contingency for the EPR gaseous carbon-14 discharges was at first estimated at 350 GBq/y, following calculations on the C-14 source term and the split of C-14 between liquid and gaseous phases (see section 7.3.1.3). The lack of operating experience feedback, and in particular of measured data (as opposed to data calculated based on power production to estimate the C-14 discharges), added to the design specifications of the EPR (TEG [GWPS] adapted from KONVOI reactor) imply that the assessment of gaseous C-14 discharges is very difficult. In particular, large uncertainties still remain on a number of points such as the nitrogen concentration of the primary circuit, the profile of discharges in the EPR, and the split of the total C-14 between the solid/liquid and gaseous phases.

Therefore, the determination of the maximum annual discharges of gaseous C-14 was difficult due to the lack of operating experience feedback data from KONVOI reactors and the limited number of measured data available for the 1300 MW(e) reactors, as opposed to calculated ones. Considering that the EPR does not present any major design improvement for the treatment and discharges of C-14, it was at first decided to base the determination of the EPR annual limit on the current 1300 MW(e) limit per unit of energy produced. This suggested an annual maximum discharge value of 900 GBq/y. This value was consistent with the highest gaseous C-14 annual discharge reported for the KONVOI reactors over the period 1995-2003 and normalised to the EPR power production (885 GBq/y normalised to 1630 GWe). However, more recent operating experience feedback data, associated with the uncertainties on the nitrogen concentration in the primary circuit (a maximum concentration of 52 ppm in the primary coolant would lead to a source term of 625 GBq/y) enabled a reassessment of the C-14 discharge estimates. It is now considered that a maximum annual discharge value of 700 GBq/y for gaseous C-14 would be more realistic. The annual expected performance without contingency is still estimated at 350 GBq/y (for a nitrogen concentration in the primary coolant of 10 ppm), but it is understood that, in the case of a higher nitrogen concentration in the primary coolant, this value would be higher.

The margin between expected performance and annual maximum discharges can be justified by the uncertainty associated with the measurement of the reported values rather than calculated, and the limited data currently available on which to base the estimation. In addition, as explained above, there is also a large uncertainty on the split between the liquid and gas discharges (currently assumed at a 20/80 ratio) and on the proportion of C-14 discharged in solid waste, which may be more favourable to liquid discharges and less to gaseous (i.e. 5/95 for example). Overall, the EPR maximum annual discharge of C-14 is set at the same level as the Sizewell B C-14 gaseous discharge limit, normalised to the power produced.

Quarterly profiles are even more difficult to predict due to the lack of OEF. It was noted that, although the production of C-14 closely follows that of power, significant variations can be observed over a whole fuel cycle.

In the light of the above operating experience feedback data (maximum quarterly value recorded for from a KONVOI unit of 340 GBq), and taking into consideration the increase in power produced and the design modifications for the EPR, a quarterly expected performance without contingency of 100 GBq/quarter, and a maximum discharge value for gaseous C-14 of 300 GBq/quarter would seem reasonable. Although these values represent a significant percentage of the expected performance without contingency and of the proposed annual discharge limit (43%) respectively, operating experience feedback from the KONVOI reactor showed that discharges over a relatively short period of time can account for a great part of the total annual discharge (up to 70%). The proposed values are thus justified from an operational point of view.

7.3.4. Influence of the current proposed limit on the radiological impact

Due to scheduling constraints, the dose received from discharges of gaseous C-14 was calculated based on the first estimate of the maximum gaseous C-14 discharges (900 GBq/y) rather than on the reviewed value (700 GBq/y). As such, the dose calculations discussed below, as well as those discussed in Chapter 11 of the PCER, are expected to represent an overestimate of the dose received. In particular, the overall dose received from gaseous discharges is expected to be lower than that discussed, since gaseous C-14 is the main contributor to the overall gaseous dose received.

It is generally considered that the total dose constraint for the most exposed member of the public from gaseous discharges (i.e. a farming family living 0.5 km from the discharge point, where adults spend 50% of their time outdoors working on land adjacent to the site, and children and infants spend 20% and 10%, respectively, of their time outdoors) is 300 $\mu Sv.y^{-1}$, and that the associated threshold for optimisation is 20 $\mu Sv.y^{-1}$.

Carbon-14 is known for having a large influence on the total dose received from liquid or gaseous discharges, and, although the annual maximum discharge value is much lower than that of tritium, its radiological impact is expected to be much higher. In addition, the impact of gaseous C-14 discharges on the total dose received depends on the speciation of this element. Since it is unclear what the split would be between the different forms of gaseous carbon, it was considered for dose calculation purposes that 100% of gaseous C-14 is released as carbon vapour (see Chapter 11 of the PCER). This scenario was considered as it is the most conservative and carbon vapour is expected to give the highest dose. This assumption, associated with the fact that the calculations are based on an early estimate of the maximum gaseous C-14 discharges (900 GBq/y) rather than on the reviewed value of 700 GBq/y, is expected to provide an overestimate of the actual dose received from C-14 gaseous discharges from an EPR unit.

In the situation considered (annual discharge of 900 GBq/y for gaseous C-14 and 100% of C-14 released as carbon vapour), the most exposed member of the public would receive a dose associated with the discharges of gaseous C-14 of 3.7 $\mu Sv.y^{-1}$ for adults, and 4.1 $\mu Sv.y^{-1}$ and 7.2 $\mu Sv.y^{-1}$ for children and infants, respectively. The greatest dose from gaseous C-14 discharges would thus be received by an infant. Even so, the dose would represent less than 3% of the dose constraint. Similarly, these doses would represent less than 40% of the threshold for optimisation (36%) for an infant, and less than 20% of this threshold for an adult. Overall, the gaseous C-14 discharges represent the main contributor to the total dose received by the most exposed members of the public from gaseous discharges, representing over 90% of the total dose for each category considered. Despite this, it must be noted that this dose is much lower than that of liquid discharges (17 $\mu Sv.y^{-1}$ for an adult) and probably constitutes an overestimate of the dose received.

7.4. GASEOUS DISCHARGES OF OTHER RADIONUCLIDES

7.4.1. Design characteristics

The Primary Gaseous Effluent Treatment System (TEG [GWPS], see Sub-chapter 6.4) is based on the Konvoï design, i.e. a semi-closed loop system for treatment of aerated effluent, which differs from the 1300 MW(e) design. In particular, this design enables better treatment of peaks in activity when switching to cold shutdown. Its main characteristics are:

- sharing of the TEP [CSTS] and REA [RBWMS] tanks cover gas: this limits the volume of the gaseous waste in normal operation by maintaining a constant gas volume when transferring water;
- continuous nitrogen flushing of the tanks cover gas: this reduces the hydrogen content, by standardising gas treatment irrespective of whether its composition contains hydrogen or oxygen;
- recycling of gases: this limits the volume of the gaseous waste in normal operation;
- recombination of hydrogen (the potential dissolution in tritium and iodine isotopes has an uncertain effect and has therefore been rejected);
- decaying the gasses (mainly xenon and krypton) on delay beds (activated charcoal tanks): this ensures 40 hours of decay for krypton 85 and 40 days for xenon (half-life of 5.25 days for 133 Xe);
- discharge via the stack as soon as a threshold pressure, which can be adjusted according to the volumes of gas to be treated, has been reached. This changes the system storage capacity.

There is no Reactor Building discharge during the cycle due to the absence of pneumatic values in the Reactor Building, except those relating to start-up of the EBA [CSVS] for in-process maintenance in the Reactor Building.

The Nuclear Auxiliary, Safeguard and Fuel Buildings can be switched to ventilation with an iodine trap. For the 1300 MW(e) plants, only some of the Nuclear Auxiliary Building rooms can be switched to an iodine trap, after passing through a very high efficiency (HEPA) particulate filter. On the EPR, all rooms, divided into “cells”, which are ventilated, are connected to very high efficiency (HEPA) particulate filters and can be switched to an iodine trap.

For the EPR unit, installing a metal skin on the internal wall of the Reactor Building limits leakage of radioactive gases into the space between the inner and outer containment (this space is maintained under negative pressure by the EDE [AVS] collection system and the extraction lines are fitted with pre-filtration and very high efficiency filtration.

Depending on the level of primary coolant activity, the gains to be reasonably expected (essentially linked to the new design of the TEG [GWPS]) may be of the order of 20% for noble gases and iodine isotopes, and of 15% for other gaseous discharges compared to 1300 MW(e) units.

However, for this type of discharge, it is very important to consider the impact of operating contingencies (e.g. leak tightness of fuel cladding) on the radiochemistry of the primary coolant and hence on gaseous discharges.

7.4.2. Noble gases discharges

7.4.2.1. Production and discharge

Radioactive noble gases are formed by fission, and comprise mainly xenon (xenon-133 and xenon-135), with a lower proportion of krypton (Kr-85). They are usually confined in the fuel but, in the event of fuel leaks, they can pass into the primary coolant via defects in the fuel cladding. Their presence in the primary coolant is also due to the occurrence of traces that can never be completely removed on new fuel assemblies following the manufacturing process. During normal operation, a portion of this coolant is let-down into the chemical and volume control system and hence to the RCV [CVCS] tank. In the latter, the fission product gases pass into the tank headspace which purges into the delay beds in the Gaseous Effluent Treatment System (TEG [GWPS]). The majority of these fission product gases have short half-lives and undergo radioactive decay in the beds. The dimensions of the delay beds are such that xenon is retained for at least 40 days (the half-life of Xe-133 is 5.25 days) and krypton at least 40 hours, ensuring sufficient decay before discharge. This minimises subsequent discharges to the environment through the gaseous effluent stack. In preparation for shutdown refuelling, there may be increased release of these fission products from the fuel and, coupled with increased let-down and clean up of the coolant, this may increase the amounts discharged.

The part of the gaseous fission products associated with the lack of leak tightness of the systems carrying the primary effluent is not treated in the Gaseous Effluent Treatment System (TEG [GWPS]). Although this part is treated by the ventilation systems of the various buildings, the HVAC filters and iodine traps have no effect on noble gases and they are therefore discharged via the Nuclear Auxiliary Building stack.

In addition to xenon and krypton, argon-41 (another radioactive noble gas) is formed during normal operation by activation of the natural content of argon-40 in the air around the reactor pressure vessel by the neutron radiation in the Reactor Building. If there is any venting of this to the outside, very low levels of this noble gas may occur in the vicinity of the plant. Its half-life is less than two hours and it therefore appears only transiently and in circumstances of Reactor Building venting. Argon-41 is collected by the Reactor Building ventilation (EBA [CSVS]), and is discharged when the ventilation is operational.

More details are given on the treatment of noble gases and iodine in the TEG [GWPS] in Sub-chapters 6.2 and 6.4, and in Figure 15.

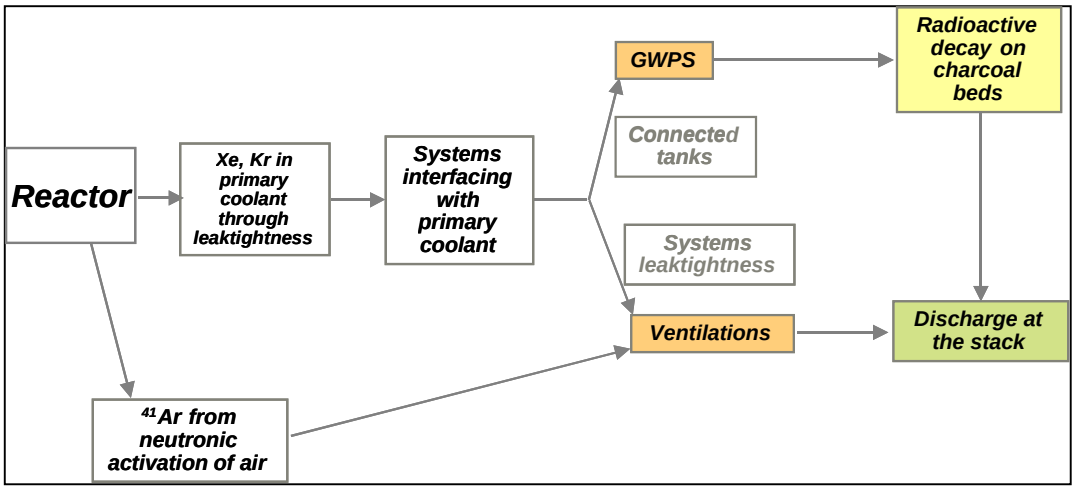

Figure 15: Noble gases treatment system

Due to the way they are formed and released, in normal operating conditions discharges of radioactive krypton and xenon are expected to be very low. However, discharges peak during unit shutdown and start-up, when large volumes of gaseous effluent are generated, needing treatment in the TEG [GWPS]. Similarly, significant discharges of these elements are expected during maintenance operations requiring the opening of systems carrying primary fluid.

The discharges of Ar-41 are associated with the start-up of the EBA [CSVS] prior to unit shutdown, and if access is required during operational phases. The discharge then occurs from the Reactor Building rather than from the TEG [GWPS].

The distribution of the various radionuclides in the discharge of noble gases was determined using the averaged discharges from all current French and German 1300 MW(e) units over the period 2002-2004 (see Table 16). The 1300 MW(e) category has been chosen as the reference, since information is readily available, and its design is as close as is available to the EPR. The reference spectrum is expected to be as follows:

Category of radionuclide	Percentage of total noble gas activity discharged
Kr-85	13.9
Xe-133	63.1
Xe-135	19.8
Ar-41	2.9
Xe-131m	0.3

Table 16: Distribution of the split of activity from noble gases discharges [Ref-1]

Overall, although a small proportion of the noble gas discharge will be continuous, the majority of the discharges will depend on operating conditions and on the stage of the fuel cycle. As such, a flat profile of the discharge over the whole cycle is not to be expected and large variations are to be seen at various points of the discharge. In addition, although the discharges are expected to be relatively low in normal operating conditions, they will be greatly affected by a number of contingencies, in particular in the case of fuel leaks.

The expected performance without contingency and the proposed annual discharge limit for the EPR noble gas discharges are 0.8 TBq/y and 22.5 TBq/y, respectively. The calculation of the EPR expected performance for the noble gas discharges has been based on the operating experience feedback data recorded for the first quartile of all the 1300 MW(e) reactors. The maximum discharge value was determined from the discharge limit from the 1300 MW(e) reactors.

7.4.2.2. Analysis of Operating Experience Feedback and factors influencing noble gases discharge

7.4.2.2.1. Annual discharges

The current annual discharge limits for noble gases for 1300 MW(e) sites are as follows:

- 45 TBq/y for Flamanville site (2-unit site);
- 45 TBq/y for Nogent site (2-unit site);
- 45 TBq/y for Golfech site (2-unit site);
- 90 TBq/y for Paluel site (4-unit site).

The operating experience feedback data for all the individual stacks at Flamanville and Paluel have been collected over the years 2002-2007. In addition, similar data have been recorded for two other sites, Golfech and Nogent sur Seine, and a KONVOI site (ISAR 2). The annual discharge data from all these sites are provided in Appendix A-35 to Appendix A-39. These figures provide the results as total discharges (in GBq), and as a percentage of the annual site discharge limit (except for the KONVOI data). In this case, only the cumulative data of all stacks on site have been considered as it was more meaningful than comparing the discharges of one unit to the overall annual site discharge limit.

Although the EPR design of the TEG [GWPS] is closer to the KONVOI design than that of the current 1300 MW(e), it was established that the annual noble gas discharges are equivalent for the existing German and French units under normal operating conditions. However, the discharges are much lower at the beginning of shutdown for the German units, mainly due to the features of the TEG [GWPS]. Despite this, the KONVOI operating experience feedback over the period studied showed values in the same range as those of the 1300 MW(e) reactor under normal operation. No major variations were observed other than that due to the normal operation of the plant.

The annual discharge data reported for the other four sites considered vary widely between around 200 GBq/y/unit and 7.5 TBq/y/unit. OEF of all 1300 MW(e) reactors over the period 2001-2003 used to establish the expected performance and maximum discharge values ranges between 0.26 TBq and 7.75 TBq for the annual noble gas discharges. Considering the number of reactors taken into account in the study and the large range of the data, this means that the discharges are very scattered depending on operating conditions. In particular, it is evident that the more active the primary effluent, the more significant the noble gas discharges become.

Values for the Flamanville, Paluel and Golfech sites are generally low and represent less than 5% of the annual site discharge limits at these sites (period 2002-2007). These values mainly represent a sum of detection limits rather than actual measured activity. The values recorded at Nogent sur Seine are much higher in comparison to those recorded at the other sites: values between 1 TBq/y/unit and 7.5 TBq/y/unit have been recorded over the period studied. The overall site highest discharge value (8.6 TBq/y) was reached in 2006 and represents 19% of the annual site discharge limit. These higher values were due to fuel issues encountered by the site over the period, and justify the need for large headroom between the predicted discharges of noble gases without contingencies and the annual limits proposed.

7.4.2.2.2. Monthly discharges

Monthly discharge data for the four 1300 MW(e) and KONVOI sites studied have been plotted in Appendix A-40 to Appendix A-45. All these data show large discrepancies in the discharges from noble gases. At Flamanville, the discharges of each unit were mostly low over the period studied, below 50 GBq/month. This is understood to be mainly due to the recording of detection threshold values rather than actual measurements and therefore it is highly likely that the activity recorded is an overestimation of the activity actually discharged. However, on a number of occasions, the monthly discharges drastically increased, reaching up to 550 GBq/month/unit. A similar behaviour was observed at Paluel, where, although most of the discharges were also below 50 GBq/month/unit, a number of peaks were present, reaching up to 1.1 TBq/month/unit. Cumulatively over a year, these high monthly values represent over 50% of the total activity discharged during the year considered.

This behaviour is significant and illustrates the dependence of the noble gas discharges on operating contingencies. Indeed, significant issues with fuel, such as fuel leaks, were not reported for either of these two sites (Flamanville and Paluel), and therefore large variations of the discharges were not expected. Even so, the range of monthly discharges varied from a factor of 1 to 20. Despite this, the highest monthly discharge recorded at Paluel was still very low in comparison to the site annual discharge limit. The situation at ISAR 2 was closer to the profile expected. Although monthly variations can be seen, the extent of these is much lower than those observed at Paluel and Flamanville. No operational contingencies that could have affected the discharge of noble gases were reported over the period studied, and therefore the profile is close to that expected.

It has already been established that the noble gas production and therefore discharges, are highly sensitive to the operating conditions, and, in particular, to any contingency associated with fuel leaks. In order to quantify this sensitivity and determine the influence of such operating conditions, the operating experience feedback of two other 1300 MW(e) sites, Nogent and Golfech, was studied. These sites have been chosen as they have experienced a number of issues with fuel management during the period studied, and in particular fuel leaks.

The profile obtained at Golfech is similar to that observed at both Flamanville and Paluel. The noble gas discharges are mostly very low over the period, but, on two different occasions (one for each unit), a peak of discharge is observed (see Appendix A-43). Both these peaks are due to higher discharges of Xe-133 from the unit, and have a huge impact on the total annual discharges. At Golfech 2, the highest monthly discharge (February 2003) accounted for over 50% of the total noble gases discharges from this unit in 2003. At Golfech 1, the highest monthly discharge recorded in June 2005 (1.4 TBq) accounted for over 90% of the unit's yearly discharge of noble gases. These two events provide evidence of the large impact of contingencies on both the monthly and annual discharges.

The Nogent site has encountered significant fuel issues over the period, and this is reflected in the discharge of noble gases for both units (see Appendix A-44). Indeed, the background discharge for both units is higher than that observed at any of the other 3 sites, and the monthly discharges fluctuate much more than for any of the other sites considered. On a significant number of occasions (about 20 over the 5-year period considered), the monthly discharges of either or both units exceeded 500 GBq, reaching up to 3.8 TBq (Nogent 2, June 2006). This maximum value is equivalent to about 8.5% of the annual site discharge limit, and, considering the maximum discharge value proposed for the EPR, such a discharge would represent about 17% of the EPR annual limit for noble gases (see below). In addition, this maximum value also accounts for up to 60% of the unit's total discharge of noble gases over 12 months (rolling year June 2006 to May 2007, discharge over 12 months = 6.43TBq).

7.4.2.3. Noble gas quantitative targets

The calculation of the EPR expected performance for the noble gas discharges was based on the operating experience feedback data recorded for the first quartile of all the 1300 MW(e) reactors, and the annual maximum discharge value was transposed from the 1300 MW(e) reactor limit. The expected performance without contingency and the proposed annual maximum discharge value for the EPR noble gases discharges were thus estimated at 0.8 TBq/y and 22.5 TBq/y, respectively.

Overall, the above analysis of OEF provides evidence that the 0.8 TBq/y target for the EPR annual expected performance without contingency is very ambitious, and could only be reached if no fuel issues were encountered, and if no access to the Reactor Building is required during the operational phase. For example, such a target could have been reached at Flamanville, Paluel and Golfech over the period studied (2002-2007), but only for some of the units considered. This would never have been achieved at Nogent.

It is undeniable that the headroom between the EPR expected performance (0.8 TBq/y) and the proposed annual limit (22.5 TBq/y) is very significant. However, it has been demonstrated above, using 4 different 1300 MW(e) sites, that the contingencies associated with the reliability of the fuel can have a very large impact on the noble gas discharges. Considering the current annual discharge limits in force for the 1300 MW(e) reactors, it does not seem unreasonable to keep the same limit for the EPR, which is equivalent to a 25% improvement per unit of energy produced. In addition, since the impact of noble gases on the total dose received from gaseous emissions is small, a reduction in the limit would not have a significant impact on the dose. Moreover, these values are already considered low in comparison to other sites across the world, and represent only about 50% of the discharge limit at Sizewell B normalised to 1000 MW(e) (25.2 TBq/y at Sizewell B vs. 12.97 TBq/y for the EPR).

In normal operating conditions (i.e. without fuel leaks or any other contingencies), it is expected that the EPR monthly discharges would actually be below the limit of detection, and thus that the values recorded would only represent the sum of detection thresholds. Typically, this could be as low as 400 GBq/month. Considering the monthly discharges recorded at Nogent and Golfech and the contingencies associated with fuel defects, it can be assumed that the noble gas monthly discharges could reach up to 5 TBq/month for the EPR. Indeed, it was established that discharges of noble gases over a short period of time can greatly impact the overall discharge over 12 rolling months, as was the case at Golfech in 2005 when 90% of the total annual activity was discharged in one month. As such, it is essential that a significant margin remains between the expected performance and the maximum discharge value, both from a monthly and annual point of view. It is expected that this maximum value could be reached in case of fuel leaks, at reactor shutdown, and during degassing of the RCV [CVCS] and opening of the primary circuit.

7.4.2.4. Influence of the current proposed limit on the radiological impact

As mentioned previously, the current proposed annual limit for the discharge of noble gases from an EPR unit is 22.5 TBq/y. It is generally considered that the total dose constraint for the most exposed member of the public from gaseous discharges (i.e. a farming family living 0.5 km from the discharge point, where adults spend 50% of their time outdoors working on land adjacent to the site, and children and infants spend 20% and 10%, respectively, of their time outdoors) is 300 $\mu Sv.y^{-1}$, and that the associated threshold for optimisation is 20 $\mu Sv.y^{-1}$.

Although the proposed annual maximum discharge value for noble gases can be considered to be significant, it is generally reported that the overall impact of noble gases on the dose received by members of the public is relatively low. This is due to their physical and chemical properties, which prevent them being deposited, and therefore they do not enter the food chain or give rise to groundshine doses. In addition, they do not get absorbed by the lungs, and therefore do not create an inhalation dose. As such the only exposure route for noble gas discharges is through submersion in the plume.

In the situation considered (annual discharge of 22.5 TBq/y for noble gases), the most exposed members of the public would receive a dose associated to the discharges of noble gases of 4.7×10^{-2} $\mu Sv.y^{-1}$, 2.9×10^{-2} $\mu Sv.y^{-1}$ and 2.3×10^{-2} $\mu Sv.y^{-1}$, respectively, when considering an adult, a child and an infant (see Chapter 11 of the PCER). The largest part of this dose (around 45%) would be due to Xe-135.

The greatest dose from noble gas discharges would thus be received by an adult. Even so, the dose received from noble gases would only represent a fraction of the dose constraint (0.01%) and of the threshold for optimisation (0.2%). In addition, the contribution of noble gas discharges on the total dose received by the most exposed member of the public from gaseous discharges would not be significant, representing only 1.2%, 0.66% and 0.3% of the total dose received for an adult, a child and an infant, respectively.

As such, even though the proposed maximum discharge value for noble gases can be seen as high, the discharges would only have a minor radiological impact on the overall dose received by the most exposed members of the public.

7.4.3. Gaseous iodine discharges

7.4.3.1. Production and discharge

As previously mentioned in section 6.4.1.1, iodine isotopes are formed in the fuel by fission and can escape into the reactor coolant water via fuel defects. Also, like other fission products, small quantities are produced from uranium surface contamination within the reactor which can also be found in the primary coolant.

The majority of radioactive gaseous iodine isotopes are treated in the EPR in the TEG [GWPS], as part of the gaseous fission products. As seen in section 6.4.1.1, the majority of radioactive iodine isotopes dissolve in the liquid phase in the TEG [GWPS] and are thus treated on filters and demineralisers. The radioactive iodine isotopes potentially remaining in the gaseous phase in the TEG [GWPS] are treated on delay beds (see Figure 16). In addition, these treatment systems are located before the iodine traps of the Nuclear Auxiliary Building ventilation, and as such, it is expected that any iodine not retained on the delay beds will be retained by the further treatment systems.

Radioactive iodine isotopes should have a similar decay to radioactive xenons, due to the very similar atomic weights of these elements. Thus, their radioactive decay on the delay beds is estimated to be around 40 days.

Part of the gaseous fission products (and therefore part of the gaseous iodine isotopes) associated with the lack of leak tightness of systems carrying primary fluid are not treated in the TEG [GWPS]. This effluent however passes through the ventilation system in the nuclear buildings (Nuclear Auxiliary, Safeguard and Fuel Buildings) which is connected to very high efficiency (HEPA) particulate filters and can be switched to an iodine trap. The switch of the ventilation to iodine traps can be implemented either if a high activity has been detected by the KRT [PRMS], or as a preventive method during certain operations, or in case of an accident for the Safeguard and Reactor Buildings.

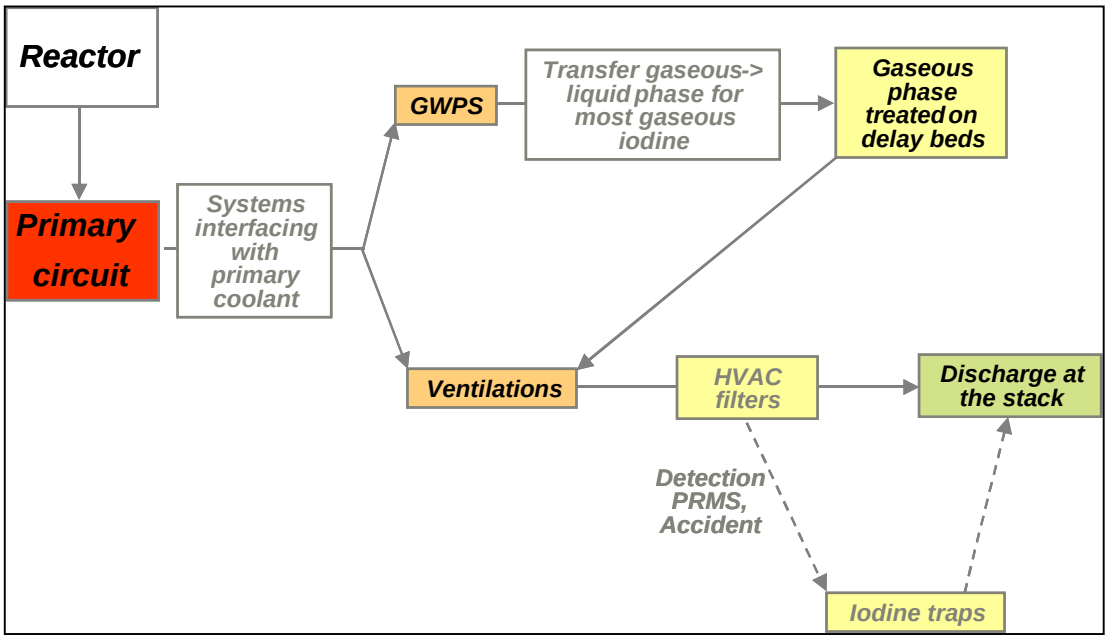

Figure 16: Gaseous iodine treatment system

Due to the multiple treatment systems for gaseous iodine isotopes implemented in the EPR, the discharges in normal operating conditions are not expected to be very significant in comparison to some other radionuclides. However, these discharges are very dependent on operational conditions and will be significantly affected in the case of leaking fuel for example. In addition, the chemistry of iodine isotopes is difficult to understand. It has been established that these elements can be retained for a period of time on systems such as paint or pipes, and be released for no apparent reason. Such discharges are unpredictable and are therefore accounted for in the various operational contingencies. Still, the part they play in the total amount of gaseous iodine discharged is difficult to quantify.

The expected performance without contingency for the EPR gaseous discharges of iodine was based on operating experience feedback data from the 1300 MW(e) reactors. The values provided by this OEF were very low and correspond to a sum of detection thresholds rather than actual measured discharge values. This is because a large number of the discharge values of the units considered were below the limit of detection over the period studied. As such, it was decided that the EPR expected performance without contingency would be in line with those of the first quartile of the 1300 MW(e) fleet, i.e. 50 MBq/y. In addition, the very low limit values for the 1300 MW(e) reactors (400 MBq/y) are amongst the most at risk from faults affecting the radiological state of the primary coolant. Thus, it is realistic to incorporate, in the determination of the EPR expected performance, a gain taking into consideration the improvements made to the TEG [GWPS], and to use the 1300 MW(e) limit for the maximum discharge value. Therefore, the EPR maximum discharge value is expected to be as low as 400 MBq/y.

7.4.3.2. Analysis of Operating Experience Feedback and factors influencing the gaseous iodine discharges

7.4.3.2.1. Annual discharges

The current annual discharge limits for gaseous iodine for 1300 MW(e) sites are as follows:

- 0.8 GBq/y for Flamanville site (2-unit site);
- 0.8 GBq/y for Nogent site (2-unit site);
- 0.8 GBq/y for Golfech site (2-unit site);
- 1.6 GBq/y for Paluel site (4-unit site).

The operating experience feedback data for all the individual stacks at Flamanville and Paluel have been collected over the years 2002-2007. In addition, similar data have been recorded for the Golfech and Nogent sites. The annual discharge data for all sites are provided in Appendix A-46 to Appendix A-49. These figures present the results as both the cumulative discharges of all stacks on site, along with the annual data per stack. They also provide the results as the total discharges (in GBq), and as a percentage of the annual site discharge limit. In this case, only the cumulative data of all stacks on site have been considered as it was more meaningful than comparing the discharges of one unit to the overall annual site discharge limit. Operating experience feedback from the KONVOI reactor has not been represented here as it is consistently below the limit of detection and thus not reported, according to German practice.

As seen before, the design of the EPR gaseous treatment system is different to that implemented on the existing 1300 MW(e) reactors, and, as such, comparison between the two may not be meaningful. In addition, operational conditions that can affect such discharges will be different in the EPR and in the 1300 MW(e) reactors. However, although a straight comparison between both designs (EPR and 1300 MW(e)) is not easy for the prediction of EPR gaseous iodine discharges, OEF from the 1300 MW(e) reactors can provide some useful information. In particular, operating experience feedback from the 4 sites considered (Flamanville, Paluel, Golfech and Nogent) shows some very different behaviour depending on the unit considered.

At Flamanville, Paluel and Golfech, most annual iodine discharges are below 50 MBq/y/unit. However, each site has at least one year where discharges of at least one of the units on site massively increased, generally reaching between 100 and 200 MBq/y/units. These increases in discharges are usually expected when fuel failures happen at a site. Under normal operating conditions without contingencies, such high discharges are not expected to be reached, as the majority of iodine isotopes are well retained in all the treatment systems implemented.

Annual discharges at Nogent are in general higher than at any of the other three sites, with values per unit between 15 MBq/y and 1.78 GBq/y. This highest value was reached before the new discharge authorisation came in force in 2005 and therefore did not break the current limit. However, this provides evidence that gaseous iodine discharges can be very high and thus that an adequate maximum discharge value is required. Three records show discharges around 200 MBq/y/unit, with others showing discharges at similar levels to that of the other stations considered above (below 50 or 100 MBq/y/unit). This example was chosen to illustrate the high dependency of the gaseous iodine discharges on contingencies and the influence of these contingencies on the overall discharges.

Although such discharges are unlikely from the EPR due to the design improvements implemented, the OEF from Nogent illustrates the very contingency-dependent nature of the gaseous iodine discharges, and the fact that the current very low limits on discharges of gaseous iodine are among the most threatened by faults affecting the radiological state of the primary coolant and fuel leaks. In addition, it is evident from the above OEF that the EPR expected performance value of 50 MBq/y could only be attained in the absence of any fuel contingency and treatment system fault. This also justifies the need for significant headroom between the EPR expected performance and the proposed annual maximum discharge value.

7.4.3.2.2. Monthly discharges

The study of the monthly operating experience feedback data (see Appendix A-50 to Appendix A-54) shows that the high annual discharges seen for some of the years and at some of the sites are usually only due to a small number of high monthly discharges in the year, rather than an overall higher baseline.

At Flamanville 2, the monthly discharges over the whole period do not exceed 5 MBq/month. Such a value is clearly very low and mainly results from records of detection thresholds, rather than actual measurements of the discharges. However, at Flamanville 1, although a large part of the most recent records are as low as those at Flamanville 2, a number of peaks were recorded, and the monthly discharges per unit reached up to 35 MBq/month (February 2003). This one-off discharge represented over 40% of the total gaseous iodine discharges from the unit over 12 months.

At Paluel, a similar profile was observed, but the highest discharges exceeded that of Flamanville. Indeed, the highest monthly gaseous iodine discharge was observed from unit 1 in February 2002 (63.6 MBq), and represented 60% of the overall annual activity discharged from gaseous iodine in 2002 from unit 1. A similar behaviour is observed at Golfech, and one event in June 2005 led to a very significant monthly discharge of iodine-132 from Golfech 1 unit (179 MBq of I-132). The total activity from gaseous iodine discharged over that short period of time was just below 200 MBq, representing 90% of the total activity discharged over 12 rolling months from gaseous iodine. Such a discharge could occur in the EPR, and would represent almost half of the proposed annual discharge limit. This also provides evidence of the very large impact of a high discharge over a limited period of time on the overall annual activity released from these radionuclides.

As such, the case of Nogent power station is a good example to provide evidence of the very fragile nature of the iodine discharges and the threat they may represent to the overall gaseous iodine discharge limit. Although the discharge authorisation for the site was renewed in 2005, the discharges have been recorded since 2002. Prior to 2005, the discharges of iodine isotopes and other fission and activation products were considered as one, and limited to 55 GBq/year. After 2005, a new limit was set for the discharges of gaseous iodine isotopes (0.8 GBq/y), thus, some records prior 2005 are above the “new” discharge limit but still allowed under the “old” discharge limit. Under these circumstances, it can be seen that although most discharges over the period studied are low and are likely to be records of detection thresholds, very high activity (up to 1 GBq/month) was discharged from Nogent 1 towards the end of 2004 and the beginning of 2005. This was due to discharges of high activity of iodine-132 and iodine-136. The study of the operating experience feedback from this unit showed that the unit considered encountered fuel leaks along with more general fuel issues at the time, and could not control its discharges of gaseous iodine. In addition, although iodine is usually well retained by the treatment systems, these discharges occurred from buildings that were not equipped with treatment systems and iodine traps. Improvements in the EPR design should prevent this happening as all building ventilation systems can be switched to iodine traps, but this example illustrates the very high dependency of gaseous iodine discharges on operational contingencies, and the fact that short-term discharges time can greatly impact the annual activity discharged from these radionuclides.

7.4.3.3. Gaseous iodine quantitative targets

The expected performance without contingency and the proposed annual maximum discharge value for the EPR gaseous iodine discharges are 50 MBq/y and 400 MBq/y, respectively. The analysis of operating experience feedback data above has shown that the current very low limit on discharges of gaseous iodine, of 400 MBq/y, is among the most threatened by faults affecting the radiological state of the primary coolant.

Gaseous iodine discharges are not expected to be high in normal operational conditions, due to the formation process of iodine isotopes and to the various treatment systems existing prior to discharge. This justifies the very low expected performance value (50 MBq/y), similar to that observed at the sites studied in absence of contingency. However, as explained above, contingencies associated with fuel leaks and faults in the treatment systems will have a major impact on the production, and thus on the discharge, of gaseous iodine isotopes. It was estimated at Penly that the gaseous discharges in presence of small fuel leaks at shutdown could lead to discharges at least 10-fold higher than in absence of fuel leaks. This effect is multiplied if the leaks are more significant. This demonstrates the sensitive issues associated with gaseous iodine discharges, as the 400 MBq/y proposed maximum discharge value does not allow for major contingencies. In addition, operating experience feedback has shown that higher discharges due to fuel leaks impacted on the future fuel cycles as well as on the cycle considered.

As such, it has been identified that this value (400 MBq/y), already very low, constitutes one of the most rigid frameworks and does not allow for a large operational margin. In addition, the margin provided between the expected performance and maximum discharge value is not considered to be very large in the light of the OEF above. Indeed, it was reported in a number of cases that a very high discharge over a very short time can represent up to 90% of the total annual gaseous iodine discharge. This means that the occurrence of two contingencies over a 12-month period could make it difficult for the site to remain below the authorised limit. In addition, this limit is very low compared to those in force at other power stations in the world, and, for example, represents just over half of the limit in force at Sizewell B normalised to 1000 MW(e) (0.42 GBq/y for Sizewell B vs. 0.23 GBq/y for the EPR).

If no such contingencies are recorded, most of the gaseous iodine discharges are expected to occur during the unit shutdown and start-up, when large volumes of gaseous effluent need to be treated in the TEG [GWPS]. Discharges are also expected during maintenance operations, when opening of the systems carrying primary coolant is required. Thus, the profile over a whole fuel cycle, even if no contingencies are met, is not expected to be flat, but to present variations depending on the various stages of the cycle.

In the light of the above operating experience feedback, and the EPR expected performance and maximum discharge values, it can be expected that, in a scenario without any fuel contingencies, the monthly gaseous iodine discharges would be around or below 20 MBq. In case of contingency (fuel leak, shutdown and failure of the gaseous effluent treatment systems such as iodine beds), it is expected that this value could reach up to 300 MBq/month, equivalent to 75% of the proposed annual maximum discharge value.

7.4.3.4. Influence of the current proposed limit on the radiological impact

As mentioned previously, the current proposed annual limit for the discharge of gaseous iodine isotopes from an EPR unit is 0.4 GBq/y. It is generally considered that the total dose constraint for the most exposed member of the public from gaseous discharges (i.e. a farming family living 0.5 km from the discharge point, where adults spend 50% of their time outdoors working on land adjacent to the site, and children and infants spend 20% and 10%, respectively, of their time outdoors) is 300 $\mu Sv.y^{-1}$, and that the associated threshold for optimisation is 20 $\mu Sv.y^{-1}$.

As mentioned in section 6.4.1.4, the main pathway leading to possible radiation dose to people from iodine isotopes is by deposition of iodine-131 onto grass, which is consumed by cows and then transferred to humans by the consumption of milk. As such, gaseous discharges are expected to have a more significant impact on the dose received than liquid discharges of iodine isotopes.

In the situation considered (annual discharge of 0.4 GBq/y for gaseous iodine isotopes), the most exposed members of the public would receive a dose associated with the discharge of gaseous iodine of 3.9×10^{-2} µSv.y^{-1}, 7.8×10^{-2} µSv.y^{-1} and 3.2×10^{-1} µSv.y^{-1}, respectively, when considering an adult, a child and an infant (see Chapter 11 of the PCER). Iodine-131 accounts for over 90% of the iodine dose.

The greatest dose from gaseous iodine discharges would thus be received by an infant, for whom gaseous iodine constitutes the second largest contributor to the dose received from gaseous discharges (after C-14). This is not surprising considering the main pathway leading to radiation dose to human from gaseous iodine discharges (through consumption of milk). Even so, the dose received from gaseous iodine discharges would only represent a small part of the dose constraint (0.1%) and of the threshold for optimisation (1.6%) for an infant. In addition, the contribution of gaseous iodine discharges on the total dose received from the most exposed member of the public from gaseous discharges would not be very significant, representing only 0.95%, 1.75% and 4% of the total dose received for an adult, a child and an infant, respectively.

However, these results (relatively low contribution of gaseous iodine discharges to the total dose received by the most exposed member of the public) need to be put in perspective compared to the low level of the discharge value for some other radionuclides considered. Indeed, the EPR proposed maximum discharge value for gaseous iodine isotopes is less than 2% of that of noble gases for example, but despite this, the contribution of these radionuclides to the dose (especially to an infant) is much higher, although not being one of the major contributors. As such, it is still important to keep the limit for the discharges of gaseous iodine isotopes as low as possible in order to prevent the local population, and the children and infants in particular, from receiving too high a dose.

7.4.4. Other gaseous discharges of fission and activation products

7.4.4.1. Production and discharge

As described in section 7.1, the “other radionuclides” category includes aerosols not dealt with in any other gaseous effluent category. In particular, they include caesium (fission products) and cobalt isotopes (activation products). Some additional radionuclides may only be periodically detected.

The activity discharged as other gaseous fission and activation products is distributed between the various radionuclides using the averaged discharges from all current French and German 1300 MW(e) units (similar to that of gaseous iodine). The split of the various radionuclides is expected to be as follows (see Table 17):

Category of radionuclide	Percentage of the activity discharged from fission and activation products
Co-58	25.5
Co-60	30.1
Cs-134	23.4
Cs-137	21.0

Table 17: Typical expected distribution of the activity discharged as fission and activation products [Ref-1]

Fission products are normally confined to fuel rods. Their presence in the primary fluid is generally associated with fuel leaks or with traces of uranium remaining on fuel surfaces after the manufacturing process (see section 6.4.2.1). The presence of activation products is generally associated to the activation of elements present or passing through the reactor core, which become activated by the neutron flux.

As seen above (see section 6.4.2), in the EPR, these radionuclides are preferentially found in the liquid phase in the TEG [GWPS], in the exchangers or compressors. As such, they will be indirectly retained on the RCV [CVCS] and TEP [CSTS] filters.

Those remaining in gaseous form are retained in the filters of the TEG [GWPS], or in the filtration system of the Nuclear Auxiliary Building ventilation. Indeed, as explained above, the ventilation systems of all nuclear buildings in the EPR are fitted with pre-filters and very high efficiency filters (HEPA), which ensure retention of aerosols. The EPR treatment system for gaseous fission and activation products is shown in Figure 17.

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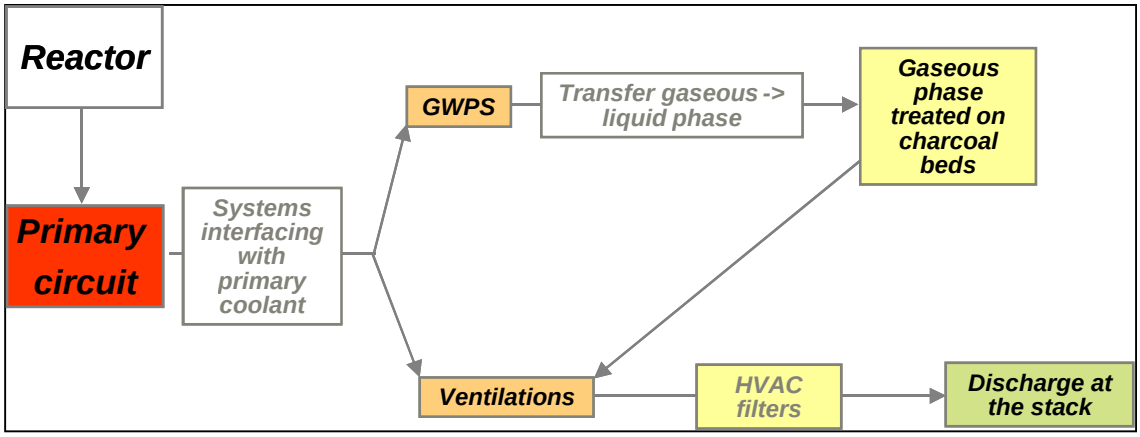


Figure 17: Gaseous fission and activation products treatment process

Similarly to noble gases and iodine isotopes, discharges from fission and activation products are generally low in normal operating conditions. In addition, the discharges from the ventilation systems of the nuclear buildings are continuous. These constitute the baseline discharges for fission and activation products, and are generally below the limits of detection. As such, the records of discharges are equivalent to a record of detection thresholds, as recommended by French practice.

However, peaks of discharges are also observed, especially during maintenance operations, both during unit shutdown and during operational phases. Thus, the profile of the fission and activation product discharges is not expected to be flat over the whole fuel cycle, but it is difficult to predict the peaks in the discharges as the profile is completely dependent on the operational contingencies and site operations. In addition, the lack of operating experience feedback for the EPR makes it difficult to predict any unplanned discharges due to maintenance operations, or the exact impact of fuel leaks on the overall discharges. However, it is evident that, due to the high dependency of the discharges on these contingencies, the gap between the EPR expected performance and the proposed annual maximum discharge value needs to be significant, as the baseline (expected performance without contingencies) is equivalent to a record of detection thresholds values.

The EPR expected performance for the annual discharge of fission and activation products is evaluated at 4MBq/y. This very low estimate was based on OEF from the French 1300 MW(e) reactors, and is considered to be equivalent to a sum of detection thresholds. The annual limit for the discharge of fission and activation products from the French 1300 MW(e) reactors is currently 400 MBq/y. In the EPR, a first estimate of the maximum discharge of other gaseous fission and activation products took account of design improvements such as the implementation of pre-filters and very high efficiency filters on the ventilation systems of all nuclear buildings, and the absence of discharge from the Reactor Building during the cycle (no pneumatic values in the Reactor Building, except those relating to start-up of the EBA [CSVS] for in-process maintenance in the Reactor Building). This led to the expectation of a reduction in the total discharge of gaseous fission and activation products of the order of 15% compared to that of a 1300 MW(e) reactor, depending on the activity present in the primary coolant, and was equivalent to a proposed annual discharge limit of 340 MBq/y. This represented a reduction of 35% in the gaseous fission and activation product discharges per unit of energy produced compared to the existing 1300 MW(e) reactors. However, the estimate for the maximum discharge value of other gaseous fission and activation products was reassessed in the light of recent operating experience feedback (see section 7.4.4.2.1) and EPR design features (such as the use of low-cobalt content material for example). The initial discharge limit of 340 MBq/y was thus reduced to 120 MBq/y in order to take into account the most recent EPR studies. The initial estimate of 340 MBq/y was nevertheless still considered for the dose calculations (see Chapter 11 of the PCER).

Considering the low impact of fission and activation products on the total dose received, it is expected that the reduction of the annual limit will not have a major impact on the overall dose calculation.

7.4.4.2. Analysis of Operating Experience Feedback and factors influencing discharges of gaseous fission and activation products

7.4.4.2.1. Annual discharges

The current annual discharge limits for gaseous fission and activation products for 1300 MW(e) sites are as follows:

- 0.8 GBq/y for Flamanville site (2-unit site);
- 1.6 GBq/y for Paluel site (4-unit site).

The operating experience feedback data for all the individual stacks at Flamanville and Paluel have been collected over the years 2002-2007. The annual discharge data for both sites are provided in Appendix A-55 and Appendix A-56. These figures present the results as both the cumulative discharges of all stacks on site, along with the data per stack. They also provide the results as the total discharges (in GBq), and as a percentage of the annual site discharge limit. In this case, only the cumulative data of all stacks on site have been considered, as it was more meaningful than comparing the discharges of one unit to the overall annual site discharge limit. Operating experience feedback from the KONVOI reactor has not been represented here as discharges are consistently below the limit of detection and thus not reported, according to German practice.

The operating experience feedback from Flamanville and Paluel shows that the annual discharges of gaseous fission and activation products are always around or below 5 MBq/y/unit, with most values recorded around 3 MBq/y/unit. Overall, the annual discharges of each of the six 1300 MW(e) units considered here were, apart from three records in 2002 at Paluel, below the EPR expected performance without contingency (4 MBq/y). These low records are mainly the result of sums of detection thresholds and it is usually understood that the actual discharge is even lower than reported. Most of the fission and activation products are found as aerosols at the stack.

Fluctuations over the years are not expected in the absence of contingency, and, although the discharge of fission and activation products is expected to be slightly higher during shutdown phases, this is not thought to significantly impact the overall annual discharge in normal operation. As explained above, the major fraction of the fission and activation products are preferentially found in the liquid phase and thus not discharged via the stacks. Those present in the gaseous effluent are well retained by the filtration systems and the Nuclear Auxiliary Building ventilation system. Aerosols are therefore never expected to be in large quantities in the gaseous effluent discharged. However, a combination of fuel leaks, maintenance operation and, above all, a failure of the treatment systems (very high efficiency filters) would lead to much higher discharges over a very short period of time, which would constitute the main contingency and could increase the discharge by a factor of 10 to 50 over a very short period. In addition, data collected over the whole fleet of reactors in France showed a large variability between the “best” and “worst” unit for the discharges of gaseous fission/activation products. For example, the highest discharges reported between 2002 and 2007 are 36 MBq at Belleville in 2007, 33.2 MBq at Saint-Alban in 2002 and 32 MBq at Gravelines in 2003. Moreover, the highest discharge reported between 1999 and 2003 in Spain was 50 MBq at Vandellos 2 in 2003. This variability between units having consistently low discharges and those having consistently high discharges is not easily explained, and is currently under investigation. This, together with the lack of operating experience feedback from the EPR, justifies the need for reasonable headroom between the expected performance without contingency (4 MBq/y) and the most recent estimate of the maximum discharges (120 MBq/y).

7.4.4.2.2. Monthly discharges

The operating experience feedback provided by the 6 units of these 2 sites shows that, as explained above, the discharges are very low under normal operating conditions. Monthly discharges of the individual units are mainly below 0.5 MBq/month (only 5.3% of the units’ monthly records exceed 0.5 MBq/month), which, considering the detection limits of the instruments used for the monitoring, is equivalent to records of detection thresholds.

These releases are mainly due to continuous discharges of aerosols, for which no improvement can be claimed for the EPR because the measurement threshold effect is combined with high volumes, and to a lesser extent to the Reactor Building discharge (for which a reduction of 15% can be claimed for the EPR).

The highest monthly discharge recorded from one unit over the period studied reached just over 1.8 MBq/month (Paluel 1, December 2007). Although this only represents a small fraction of the EPR proposed annual maximum discharge of 120 MBq/y, this high discharge over a limited period of time represents more than 50% of the total activity discharged from this unit in 2007 (3.65 MBq/y). As was the case for gaseous iodine and noble gases, this demonstrates the large impact of a single higher discharge on the annual discharges.

Considering that it has been established that the two sites (equivalent to 6 units) considered here did not encounter any major contingencies during the period studied, and, in particular, that no contingencies associated with fuel leaks or failure of the filtration systems were reported, elevated monthly discharges were not expected to be seen. It was nevertheless determined that the impact of operational contingencies (e.g. leak tightness of the fuel cladding) on the radiochemistry of the primary coolant and hence on gaseous discharges of fission and activation products (as well as noble gases and gaseous iodine isotopes) would be significant. A substantial margin is therefore needed in order to cover any operational contingencies that may affect the discharges of fission and activation products, such as fuel cladding issues combined with a failure of the treatment systems or of the very high efficiency filters that retain most of these radionuclides. In particular, it is expected that such a situation could lead to a one-off high discharge that could account for over 50% of the total activity discharged over 12 months from releases of gaseous fission and activation products.

7.4.4.3. Gaseous fission and activation products quantitative targets

The EPR expected performance for the annual discharge of fission and activation products is evaluated at 4MBq/y. This value seems reasonable in the light of the operating experience feedback data provided above. Although this value is correlated by OEF, it was established that a number of contingencies can have a major impact on the discharges.

Fission and activation products are primarily discharged during maintenance operations, whether during shutdown or not, and in normal operating conditions, they are well retained by the treatment systems. As such, a combination of fuel leaks, maintenance operation and, above all, a failure of the treatment systems (very high efficiency filters) would lead to much higher discharges over a very short period of time, which would constitute the main contingency affecting the discharges.

In the EPR, a first estimate of the effect of design improvements expected to lead to a reduction in the total discharge of gaseous fission and activation products was of the order of 15% compared to that of a 1300 MW(e) reactor, depending on the activity present in the primary coolant. This was equivalent to a maximum discharge value of 340 MBq/y, and represented a reduction of 35% of the gaseous fission and activation product discharges per unit of energy produced compared to the existing 1300 MW(e) reactors. This value was recently reviewed in the light of OEF and of the EPR design features, and reassessed at 120 MBq/y. This more realistic limit, although still presenting a large margin over the expected performance without contingency, would cover for any potential issues with fuel cladding and failure of the treatment systems that would significantly affect the discharges. Indeed, as is the case for the gaseous iodine discharges, it is expected that contingencies could increase the discharges by a factor 10 to 50 over a very short period of time. Overall, this proposed discharge limit is similar to that of Sizewell B for a higher power production. Normalised to 1000 MW(e), the EPR proposed discharge limit for gaseous fission and activation products represents about 85% of the limit currently in force at Sizewell B (0.08 GBq/y at Sizewell B vs. 0.07 GBq/y for the EPR).

Operating experience feedback provided monthly records in normal operating conditions without contingencies that were generally low and equivalent to sums of detection thresholds. Thus, it can be expected that, under normal operating conditions, the monthly discharges of gaseous fission and activation products from the EPR would be below 0.8 MBq/month.

However, the impact of monthly discharges on the total annual discharge can be large, and situations where a monthly discharge accounts for 50% of the annual activity discharged is not unrealistic (see Paluel 1 in 2007). Thus, in the event of fuel leaks combined with failure of the treatment systems, the monthly discharges would drastically increase, and it can be expected that values as high as 60 MBq/month, representing 50% of the EPR proposed annual maximum discharge value, could be reached. Large headroom is therefore required between the annual expected performance and the maximum discharge value, in addition to a large maximum monthly discharge, in order to account for the short-term effect that a failure of the treatment system would have on the discharges. However, these values are still considered to be relatively low, and considering the low impact of the fission and activation product on the dose received, the need for a large margin is not expected to be a major issue.

7.4.4.4. Influence of the current proposed limit on the radiological impact

Due to timing constraints, the dose received from discharges of gaseous fission and activation products was calculated based on the first estimate of the maximum gaseous fission and activation product discharges (340 MBq/y) rather than on the revised value (120 MBq/y). However, considering the low contribution of the gaseous fission and activation products to the overall dose received, the reduction in discharge limit is not expected to have a major influence on the total dose.

It is generally considered that the total dose constraint for the most exposed member of the public from gaseous discharges (i.e. a farming family living 0.5 km from the discharge point, where adults spend 50% of their time outdoors working on land adjacent to the site, and children and infants spend 20% and 10%, respectively, of their time outdoors) is 300 $\mu Sv.y^{-1}$, and that the associated threshold for optimisation is 20 $\mu Sv.y^{-1}$.

In the situation considered (annual discharge of 340 MBq/y for gaseous fission and activation products), the most exposed members of the public would receive an associated dose of 5.1×10^{-2} $\mu Sv.y^{-1}$, 2.8×10^{-2} $\mu Sv.y^{-1}$ and 2.6×10^{-2} $\mu Sv.y^{-1}$, respectively, when considering an adult, a child and an infant (see Chapter 11 of the PCER). The largest part of these doses (about 45%) would come from Co-60. This is not surprising as it has already been established (see section 6.4.2) that cobalt-60, due to its longer half-life, is one of the most significant radionuclides of the “other radionuclides” group. However, it is important to note that low-cobalt content materials will be used in the EPR, which has not been accounted for in the calculation of the expected performance. The implementation of these materials is expected to have a major impact on the Co-60 source term, and thus on the total dose received from gaseous activation products, the extent of which has not been assessed.

The greatest dose from gaseous fission and activation product discharges would thus be received by an adult. Even so, the dose received from gaseous fission and activation product discharges would only represent a small part of the dose constraint (0.01%) and of the threshold for optimisation (0.25%) for an adult. In addition, the contribution of gaseous fission and activation product discharges on the total dose received by the most exposed members of the public from gaseous discharges would not be very significant, representing only 1.2%, 0.65% and 0.34%, respectively, of the total dose received for an adult, a child and an infant.

Even though the contribution of gaseous fission and activation product discharges to the total dose received by the most exposed member of the public is relatively low, this needs to be put into perspective compared to the low level of the maximum discharge value for some other radionuclides considered. The EPR proposed maximum discharge value for gaseous fission and activation products is less than 2% of that of noble gases for example. However, the contribution of these radionuclides to the dose is much higher, although they are not one of the major contributors. As such, it is a legal requirement to keep this limit as low as possible in order to prevent the local population from receiving a too high a dose, and the recent review and reduction of the proposed limit from 340 MBq/y to 120 MBq/y reflects the efforts made to keep to dose as low as possible.

7.5. GASEOUS DISCHARGES – CONCLUSIONS

Generally speaking, the main contingencies having a significant impact on the discharges of gaseous effluent are associated with issues related to leak tightness of the fuel cladding and/or failure of the effluent treatment systems. In particular, these would have a major impact on the discharges of gaseous iodine isotopes, noble gases and other fission and activation products. For all these radionuclides, the headroom between the EPR expected performance without contingency and the proposed maximum discharge value needs to be significant in order to account for any such contingency. The discharges of these elements are low in normal operating conditions (mainly due to the continuous discharge from ventilation systems) but peak during shutdown, start-up, and maintenance operations. Discharges can also appear to be significant due to unexpected release of the elements retained on the surface of pipes or tanks.

As demonstrated above, in a similar manner to liquid discharges, establishing a predictive monthly profile for gaseous radioactive discharges for the EPR proves to be a very difficult task. Indeed, the lack of operating experience feedback, along with the high dependency on operating conditions and contingencies of some of the discharges makes the monthly discharges difficult to predict with accuracy for a set of given conditions. A summary table of the proposed data is given in Appendix B-2.

In addition, cautious use of operating experience feedback from the 1300 MW(e) reactors needs to be made. Indeed, following the difference made by the liquid treatment systems, significant changes have been made to the EPR Gaseous Waste Processing System (TEG [GWPS]) compared to that implemented on the existing 1300 MW(e) reactors, and thus a direct comparison of the expected performance and maximum discharges between the reactors can be difficult.

Another major difference between liquid and gaseous discharges is that most gaseous discharges are continuous, and therefore the impact of site management policy on the gaseous discharges is minor compared to that on liquid discharges. However, the monthly gaseous discharge profiles cannot be expected to be flat over a whole fuel cycle, as some radionuclides (such as fission and activation products for example) are mainly released during shutdown or start-up operations, due to contingencies involving issues with leak tightness of the fuel cladding or failure of the effluent treatment systems. Finally, issues arise with the monthly discharges of gaseous C-14. Indeed, only quarterly records are available from the 1300 MW(e) reactors. In addition, these records mostly present calculated values that might be under or over estimated compared to the actual discharge values.

Tritium:

As mentioned above, tritium production is almost directly linked to power production, although specific conditions of the primary circuit (in particular the boron content) can influence its production. The main discharge of gaseous tritium is due to evaporation from the storage pools, and tritium is released through both ventilation systems and stacks. These discharges are greatly influenced by a number of factors, including meteorology that can affect the evaporation rate of the pools.

There are no current treatment systems to limit gaseous tritium discharges, and, as such, all gaseous tritium produced is discharged into the environment. In spite of this, although tritium represents the second largest contributor (after C-14) to the dose received by the most exposed members of the public, it was estimated that the dose received from gaseous tritium discharges represents less than 5% of the total dose received from all gaseous discharges and thus is not considered significant.

The EPR performance without contingency for the discharge of gaseous tritium is expected to be around 0.5 TBq/y. Considering the good understanding of the source term and the absence of major factors that may potentially influence the discharge, the annual profile of the gaseous tritium discharges are considered to reasonably follow the production profile. However, a reasonable margin is required in order to take account of the differences implemented in the EPR regarding the management of the primary effluent, the fact that no operating experience feedback is currently available and the effect of potential contamination of the storage pools that would remain for a long time (and be seen in the discharges over several cycles). As such, it was estimated that an annual limit of 3 TBq/y would provide an adequate margin to cover all potential operational contingencies.

In the light of these considerations, and considering the EPR increase in power production (and hence the expected higher production of tritium) compared to both the 1300 MW(e) and N4 designs, and balanced by the improvements provided in the EPR (e.g. refrigeration of the gaseous tritium sampling unit providing a better accuracy of the measurement), a maximum monthly discharge value of 300 GBq/month for the EPR would seem reasonable in normal operating conditions. This is equivalent to 10% of the proposed annual maximum discharge value.

Carbon-14:

As for tritium, C-14 production is closely linked to the power production. Carbon-14 gaseous discharges represent the majority of C-14 discharges, and most of the total activity discharged by gaseous effluent. During shutdown periods, gaseous C-14 discharges are associated with the ventilation of the Reactor Building.

The EPR design differs significantly from the current 1300 MW(e) reactors in the fact that the RCV [CVCS] tank is under a nitrogen atmosphere as opposed to a hydrogen atmosphere.

Due to the continuous nature of the production and discharge of C-14, the discharges come from the Reactor Building ventilation systems during normal operation and reactor shutdown, as well as from the TEG [GWPS] during shutdown, start-up, and maintenance operations on the storage tanks connected to the TEG [GWPS]. Considering the lack of monthly records from operating experience feedback, and only the availability of quarterly calculated records, it is impossible to estimate a monthly profile for these discharges. As such, only quarterly discharge data have been estimated.

Similarly to tritium, there are no current systems for the treatment of gaseous C-14 discharges. It is therefore expected that all C-14 produced will be discharged into the environment, and, as mentioned before, that most of it will be as gaseous discharges. This, together with the fact that C-14 is known for having a large influence on the total dose received from liquid or gaseous discharges, makes C-14 the main contributor to the dose received by the most exposed members of the public from both liquid and gaseous discharges. In particular, C-14 gaseous discharges represent more than 90% of the total dose received for each age group considered (adults, children and infants).

Calculated estimates based on the characteristics of the EPR and on the assumption that 80% of the total C-14 is discharged in gaseous phase lead to an expected performance without contingency of 350 GBq/y for a nitrogen concentration in the primary coolant of 10 ppm. However, additional scenarios involving higher concentrations of nitrogen in the primary coolant lead to higher values of the expected performance without contingency (below 500 GBq/y, corresponding to the 52 ppm scenario). In all cases, the lack of reliable measured data for the discharges of C-14 (reported data were calculated until recently as opposed to measured) associated with the lack of operating experience feedback for the EPR imply that a large margin is required in order to allow for operating contingencies. In particular, the design differences between the existing 1300 MW(e) reactors and the EPR generate large uncertainties in the fluctuations observed over a fuel cycle. Indeed, it is expected that, due to the continuous degassing of the pressuriser in the EPR, the discharges will more closely follow the energy production. This is not the case in the 1300 MW(e) reactors where most of the gaseous C-14 is discharged during shutdown (during degassing of the TEP [CSTS] or of the pressurisers). In order to cover these contingencies, the maximum discharge value was at first calculated on the basis of the 1300 MW(e) limit normalised to the EPR power produced. This led to an annual maximum discharge value of 900 GBq/y, based on the 700 GBq/y limit for the 1300 MW(e) reactors. This value was recently reviewed in the light of OEF and reduced to 700 GBq/y, which should still include the uncertainty on the split of C-14 between the different effluent phases (currently assumed to be 20/80 liquid/gaseous, see sections 6.3.2.1 and 7.3.1.3) or the concentration of nitrogen in the primary coolant. This is equivalent to the current discharge limit for Sizewell B normalised to the power produced.

In the light of operating experience feedback data, and taking into consideration the increase in power produced and the design modifications for the EPR, a quarterly maximum discharge value for gaseous C-14 of 300 GBq would seem reasonable. Although this represents a large percentage of the expected performance without contingency, it is understood that such a maximum value could be reviewed once sufficient operational data become available.

Iodine, noble gases and other radionuclides:

All these radionuclide categories are largely affected by operating contingencies, fuel leaks and, in particular, potential failures of treatment systems. Therefore, estimating a monthly discharge profile over a fuel cycle is not possible. In normal operating conditions, production and discharges are expected to be very low, and although some discharges are continuous from the ventilation systems, the main fraction of the discharges is expected to occur during reactor shutdown and maintenance operations. However, in the event of fuel leaks, the production and discharge sharply increase.

Discharges from gaseous iodine isotopes and other gaseous fission and activation products are expected to be very low under normal operating conditions, and records are more likely to represent a collection of detection thresholds rather than actual measured values. However, in the event of contingencies, the discharges are expected to sharply rise and could reach several hundreds of MBq. Nevertheless, the impact of the dose received from these radionuclides on the overall dose received by the most exposed members of the public is expected to be low, and these radionuclides do not constitute the major contributors to the total dose received. An annual performance without contingency of 50 MBq/y and 4 MBq/y is expected for the gaseous discharges of iodine isotopes and fission and activation products, respectively. As mentioned above, these values mainly constitute a sum of detection thresholds rather than measured values. However, it is estimated that these discharges could be 10 to 100 times higher in the presence of fuel leaks associated with failure of the treatment systems (iodine beds for the iodine discharges and very high efficiency filters for the fission and activation products). Thus, an annual maximum discharge value of 400 MBq/y is proposed for iodine discharges, and of 120 MBq/y for fission and activation products discharges. The iodine maximum discharge value is the most stringent, and represents a real threat as it only allows for minor operating contingencies. The maximum discharge value for fission and activation products was recently reviewed and the initial estimate was reduced from 340 MBq/y to the current 120 MBq/y proposed. In both cases (iodine and fission and activation products), the proposed discharge limits are lower than those currently in force at Sizewell B, normalised to 1000 MW(e).

In the light of the operating experience feedback for gaseous iodine and the EPR expected performance and maximum discharge values, it can be expected that, in case of contingency (fuel leak associated with failure of the treatment systems), a large part of the EPR annual maximum discharge could be discharged in a month. A value of 300 MBq/month, representing 75% of the annual maximum discharge, would be a realistic estimate.

Similarly, the monthly discharge of gaseous fission and activation products from the EPR can significantly impact the overall annual discharge. Thus, in the presence of contingencies, the monthly discharges of gaseous fission and activation products would drastically increase, and it can be expected that values as high as 60 MBq/month, representing 50% of the EPR proposed annual maximum discharge value, could be reached.

The profile of the discharges of noble gases is similar to that of iodine isotopes and other fission and activation products, but the activities are much higher. However, the overall impact of these radionuclides on the total dose received by the most exposed members of the public is generally considered as not significant, even though the maximum discharge value proposed for the EPR is much higher than for other radionuclides. This is due their physical and chemical properties: they are not deposited, and therefore do not enter the food chain or give rise to groundshine doses. In addition, they are not absorbed by the lungs, and therefore do not give rise to an inhalation dose. As such the only exposure route for noble gas discharges is through submersion in the plume.

Low annual discharges are expected during normal operation. However, the absence of treatment systems to prevent discharges of noble gases in case of contingency (mainly fuel leaks) may lead to much higher discharges during reactor shutdown period, which could significantly impact the annual releases. An annual maximum discharge value of 22.5 TBq/y is therefore proposed in order to cover such contingency. Although this margin can be seen as large, the overall impact of noble gases of the dose received is minimal. In addition, this limit would only represent just over half of the limit at Sizewell B normalised to 1000 MW(e).

In normal operating conditions (i.e. without fuel leaks or any other contingencies), it is similarly expected that the EPR monthly discharges would actually be below the limit of detection, and therefore that the values recorded would only represent the sum of detection thresholds. However, considering the OEF studied and the contingencies associated with fuel defects and the absence of treatment systems for noble gases, it could be assumed that the noble gas maximum monthly discharges could reach up to 5 TBq for the EPR in the presence of contingencies. This would represent almost 20% of the EPR annual maximum discharge value, and therefore justifies the need for significant headroom between the expected performance and proposed maximum discharge value.

8. CHEMICAL EFFLUENT DISCHARGES

This paragraph deals in part with requirement 3.2 of the EA P&I Document.

Whether they are associated with liquid radioactive effluent (lithium hydroxide and boron for example) or derived from the operation of non-nuclear parts of the installation (conditioning amines from the secondary system for example), chemical discharges are also subject to a systematic approach to optimisation and reduction.

Thus, the EPR follows the overall approach taken for the current operating units as regards controlling reductions of chemical discharge (see, for example, hydrazine).

Detailed estimates have been made, setting down the assumptions, the volumes, concentrations etc. In particular maximum values have been derived for scenarios to meet a request from regulators [Ref-1].

8.1. CHEMICAL DISCHARGES ASSOCIATED WITH RADIOACTIVE EFFLUENT

8.1.1. Boric acid

The discharge of boric acid, which is used to control the nuclear reaction, depends on the production of effluent from the primary system (primary system dilution operations, drainage for maintenance...).

Reduction of boron discharge naturally depends on optimising operating practices, but also to a large extent on the initial design. As such, the main design characteristics of the EPR are:

- increased recycling of the primary liquid effluent aerated in the TEP [CSTS] (compatibility of the TEG [GWPS] with aerated gaseous effluent): boric acid discharge for the EPR should fall as a result by at least 10% compared to 1300 MW(e) reactors, consistent with the reduction in liquid effluent;

- the use of boron enriched with B-10 (30 to 40% atomic) whereas in 1300 MW(e) and N4 facilities, the isotopic concentration is 19.9 (natural boron isotope): this design characteristic leads to a boron concentration which can be up to 30% lower than those encountered today in operation (for a high enrichment, typically of the order of 37% atomic);

- the smaller volume of the REA [RBWMS] boron tanks (100 m^3 instead of 130 m^3), and the boron concentration (7000 ppm instead of 7500 ppm, which follows from using enriched boron), which reduces the impact of discharge from a polluted REA [RBWMS] boron tank. This is taken into account in the maximum discharge scenario;

- addition of tanks and pumps in various areas, to improve the collection of primary effluent.

Finally, (although this is not specific to EPR), if a desalination plant is installed for the EPR project, this will provide make-up water with a lower concentration of silica, which over the long-term will lead to a reduction in boron discharge arising from the blowdown of silica from the primary coolant.

The average discharges of boric acid per site for 2001 – 2003 for the 1300 MW(e) units show a wide variability in operation; the values arrived at (in kg/unit/year) are: Minimum: 3200; Maximum: 10,900; Average: 6430 ([Ref-1] [Ref-2]). The 1st quartile between 3200 and 3700 has been selected at 3200.

The estimate of actual discharge of boric acid, i.e. expected performance excluding contingency, is obtained by applying the above gains (10% via increased recycling, 30% via Boron enrichment) to the reference chosen (1st quartile from feedback 1300 MW(e)) of 3.2 te, or **2 te/year.**

For the maximum discharge, which must take into account any possible operating contingencies (e.g. discharge from a polluted REA [RBWMS] boron tank), application of the usual scenarios for the EPR give a maximum discharge evaluated at **7 te/year**.

The capacity of the TEP [CSTS] is calculated to avoid unnecessary discharges. More details on the storage capacity are available in PCSR Sub-chapter 9.3, section 3.2.1.1.

8.1.2. Lithium hydroxide

Lithium hydroxide, which is used to maintain the $pH_{300°C}$ in the primary coolant according to the boric acid concentration, can be considered well recycled in the primary circuit, as it is retained in the TEP [CSTS] and 8TEU [LWPS] demineralisers. Discharge is very low (< 1 kg/year/unit) and the situation in the French NPP fleet is considered to be optimised [Ref-1].

The EPR design is different in that there is:

- increased recycling of primary gaseous effluent via the RPE [NVDS] and the TEP [CSTS], which, as for boron discharge, reduces discharge of lithium hydroxide;

- a design allowing complete lithium recovery through trapping in a mixed bed ion exchanger located upstream of the 8TEU [LWPS] treatment: once it is saturated with lithium, this mixed bed will replace the one fitted on the RCV [CVCS] discharge line. Except in the case of operating incidents (such as “demineraliser breakdown”), the lithium is almost never released from the process in liquid form;

- the lithium concentration is expected to be set at 4 ppm (see Sub-Chapter 5.5 of the PCSR), higher than 2.2 ppm (low lithium chemistry in GEMMES management of the 1300 MW(e) reactors) as a result of the compromise with dose reduction requirements, whereby fewer activated corrosion products are produced if the primary circuit $pH_{300°C}$ is kept close to 7.2. This characteristic does not hinder normal operation (the lithium hydroxide is retained on the demineralisers of the TEP [CSTS] and the 8TEU [LWPS]), but limits the maximum discharge in the event of an operating contingency.

NB: Automatic injection of lithium (to constantly meet the primary $pH_{300°C}$ setpoint in the lithium / boron diagram) changes nothing compared to manual injection, in terms of liquid discharge of lithium hydroxide.

Given these design elements:

- the expected EPR performance excluding contingency corresponds to a discharge which cannot be measured (well below 1kg / year / unit);
- the maximum discharge (according to the usual scenarios of operating contingencies) is of the order of **4.4 kg/year/unit** [Ref-2].

8.1.3. Zinc acetate

Zinc acetate is injected into the EPR primary circuit to reduce material corrosion and cobalt deposition on the surfaces (see PCSR Sub-chapter 5.5).

Based on international and EDF feedback, zinc injection has no negative impact on the waste/discharge production. Conversely, the zinc injection is expected to contribute to reduction of the source terms and consequently to contribute to minimisation of corrosion products discharges [Ref-1].

The depleted zinc acetate injection does not affect the chemical/radiochemical discharges due to the fact that [Ref-2]:

- Acetate is an organic molecule with a short life in the temperature and neutron/gamma flux environment of the RCP [RCS].
- Assuming that the acetate remains in the RCP [RCS] and reaches the RCV [CVCS], it will be decomposed at low temperature into CO_2 and bicarbonate (HCO_{3^-}). The CO_2 will then be removed by the Volume Control Tank (VCT) degassing and the bicarbonate will be retained by anion resins.
- The depleted zinc enables to ensure the low production of Zn-65.

8.1.4. Hydrazine and conditioning amines: morpholine, ethanolamine, ammonia

As regards the secondary system, design improvements made to the EPR unit aim to reduce leakage from equipment in the turbine hall, by improving its leak tightness. In addition, as for facilities currently in operation, the following arrangements have been made: morpholine conditioning, then possibly passage in ethanolamine and break down of the hydrazine, in the 0KER [LRMDS] tanks. As indicated in Sub-chapter 5.5 of the PCSR, the use of the different amines is possible for the UK EPR.

Nitrogen discharge forecasts for the EPR should be similar to those of the 1300 MW(e), be it for hydrazine, morpholine or ammonia, assuming that APG [SGBS] resins saturated by amines are used, as on the N4 facility.

For design and material reasons, there are two possible cases:

1) for chemical morpholine treatment with the addition of ammonia (or ethanolamine), there is no benefit in regenerating APG [SGBS] resins. The use of APG [SGBS] resins in non-regenerated mode (as installed on sites in operation) is the best option for discharge and waste;

2) for high pH, ammonia treatment, the small difference in affinity between ammonia ions and sodium ions would require resins to be replaced or regenerated at best every 1.5 weeks. For waste reasons (and economic reasons), it is unacceptable to replace APG [SGBS] resins at this rate, so regeneration is necessary:

    - for chemical regeneration, significant discharge of sulphate and sodium should be anticipated, as should volumes of water corresponding to phases of lifting, dilution of reagents, moving and rinsing of resin beds; and

    - with electro-regeneration, chemical regeneration discharge is almost nil, but the volumes of water discharged are higher than for the chemical solution.

If high pH ammonia treatment can be avoided, morpholine treatment (with additional ammonia) is preferable, prior to any passage in ethanolamine (with or without additional ammonia).

Ethanolamine is a substitute reagent whose increased efficiency (at the same pH, ethanolamine has a better dissociation coefficient than morpholine) means a smaller quantity needs to be injected for chemical treatment, and nitrogenous discharges which are theoretically estimated at 30% are lower than those of morpholine.

8.1.4.1. Hydrazine

Hydrazine is discharged by both the 0KER [LRMDS] and 0SEK [SiteLWDS]. 0KER [LRMDS] discharge originates from non-recycled APG [SGBS] blowdown and SG drainage following wet conditioning of the SG during shutdown. 0SEK [SiteLWDS] discharge originates from normal operation, hot drainage of the feedwater plant, and feed and bleed on restarting.

The EPR design is different as the design takes account of the destruction of the hydrazine (in the 0KER [LRMDS]) before discharge, either by heat degradation or by treatment in the 0KER [LRMDS] reservoirs.

Taking into account various discharge scenario initial conditions, the volume of non-recycled APG [SGBS] blowdown, the average concentration in non-recycled APG [SGBS] blowdown, the average concentration in 0SEK [SiteLWDS] during operation and during hot drainage, and the 0SEK [SiteLWDS] volume discharged, etc. leads to a **maximum annual discharge estimated at about 14 kg / year / unit** ([Ref-1] to [Ref-3]).

The expected performance excluding contingency assuming volume-optimised 0SEK [SiteLWDS] discharge and attention to the leak tightness of hydrazine injection pumps, is **7 kg / year** ([Ref-1] to [Ref-3]).

8.1.4.2. Morpholine, ethanolamine, ammonia, nitrogen discharge

Discharge occurs in both the 0KER [LRMDS] and 0SEK [SiteLWDS]. 0KER [LRMDS] discharge originates from non-recycled APG [SGBS] blowdown and SG drainage following wet conditioning. 0SEK [SiteLWDS] discharge originates from normal operation, hot drainage of the feedwater plant, and treatment on restarting.

8.1.4.2.1. Morpholine or ethanolamine conditioning

For this discharge, there are no EPR design modifications. Also, for morpholine or ethanolamine conditioning, the estimates for the EPR of the maximum discharge or the expected performance excluding contingency are based on scenarios, almost identical to those of the 1300 MW(e) facilities in operation, which, depending on the treatment, give:

Morpholine:

- maximum discharge of the order of 840 kg/year/unit;
- expected performance excluding contingency of the order of 345 kg/year/ unit.

Ethanolamine:

- maximum discharge of the order of 460 kg/year/ unit;
- estimated actual discharge excluding contingency of the order of 250 kg/year/ unit.

As regards **total maximum nitrogen discharge**, by including non recycled APG [SGBS] blowdown and SG drainage in the 0KER [LRMDS], and the secondary circuit flow excluding CVI (condenser vacuum), the estimate (in nitrogen) is **5060 kg / year.**

8.1.4.2.2. High pH ammonia treatment

High pH ammonia treatment (maintaining a high pH requires a significantly higher ammonia concentration) presents a new situation as regards nitrogen discharge. The possibilities of recycling or concentrated ammonia treatment in the reservoirs of the condenser vacuum system (CVI) have been examined (see below), in order to reduce nitrogen discharge levels to those of morpholine or ethanolamine treatment.

The first method would be to return the fluid to the condenser. However, this process has not yet been shown to have adverse effects (e.g. a deterioration of physical-chemical properties on SG blowdown).

The other method consists of treatment of the effluent from the CVI in an evaporator: the industrial feasibility of this concept is currently being studied.

Other innovative methods are also being studied.

The first two methods, which may be used in conjunction if necessary, are only at the preliminary investigation stage. Further medium term development is required as a minimum, if high pH ammonia treatment were to be adopted.

8.1.5. Trisodium Phosphate

Used as a corrosion inhibitor (basic pH) for chemical treatment mainly of the RRI [CCWS] and SRI (conventional island component cooling water systems) systems (Sub-chapter 5.5 of the PCSR), the phosphate (in the form of trisodium phosphate: Na_3PO_4) is among the chemical discharges particularly monitored because of its potential for eutrophication. Reducing its discharge is one of the environmental goals of the EPR.

Phosphate discharge forecast for the EPR should show an **improvement of about 30%** compared to the 1300 MW(e) facilities [Ref-1], all things being equal, due to design provisions which provide for carbonation of the phosphate by atmospheric CO_2, via the installation of hydraulic seals, in the RRI [CCWS] and SRI systems; the expected consequences of which are: lower phosphate concentrations to obtain the same pH and fewer system blowdowns (make-up and discharge) to combat the effects of carbonation.

As such, the main design characteristics of the EPR are:

- integration in the design of SRI (conventional island component cooling water systems) and RRI [CCWS] of hydraulic seals, linked to the air inlets, as anti-carbonation devices hence limiting the volume of make-up and discharge required to maintain the pH;
- the volume of the RRI [CCWS]: the EPR volume is about 60% higher than that of the N4 (450 m^3 compared to 260 m^3). However, its design in 4 divisions, with no shared areas between pairs of divisions, partly offsets the effect of this increase on the volume of discharge if half of the RRI [CCWS] is polluted.

The estimate of the phosphate discharge is based on 5 components:

- flow to the 0KER [LRMDS] of RRI [CCWS] drainage for radioactive pollution dilution (1.5 volumes RRI [CCWS] or 1.5 * 450 m^3), only taken into account to estimate the maximum discharge;
- flow to the 0KER [LRMDS] of TRI, EVU [CHRS], 8TEU [LWPS] and DER, DEL [SCWS], DEQ (chilled water production) systems (20 kg, value from operational experience);
- flow of 75 m^3 to 0SEK [SiteLWDS] for treatment of SRI drainage;
- flow to 0SEK [SiteLWDS] of 4 volumes of SRI to replace leaks from pump seals;
- flux to 0SEK [SiteLWDS] of one RRI [CCWS] replacement volume for treatment.

Average and maximum estimated values are lower than those currently encountered in operation in the fleet because of the anti-carbonation features in the EPR design.

The maximum concentration used for design purposes is 500 mg/l (expressed in PO_4^{3-}) and this is also used currently in the discharge scenarios. Due to the hold-down devices in the EPR design, an average concentration of 250 mg/l has been used to establish the maximum discharge value and a value of 175 mg/l to establish actual discharge [Ref-2] [Ref-3].

Taking into account these optimisations as part of usual discharge scenarios applied to EPR gives:

- estimated actual discharge excluding contingency of **155 kg/year**;

- maximum discharge of the order of **400 kg/year**.

8.1.6. Summary of chemical discharges

This approach means that the documentation gives realistic values for the discharges corresponding to expected performance (excluding significant contingency); and maximum values that are reasonably likely to encompass the amounts of chemicals discharged in the various situations that could be encountered at the site, as for liquid radioactive effluent.

The EPR 24 hour flows are determined from the maximum concentration in the T tanks (0KER [LRMDS]) and Ex tanks (0SEK [SiteLWDS]) (depending on the substance, these flows correspond to discharge from one T tank and one or several Ex tanks, which could contain various types of effluent mix). They are not detailed in the table below as they are also dependent on the other units on site.

The table below shows the expected performance excluding contingency; the maximum amounts, and the characterisation of chemicals associated with radioactive effluent that will be discharged [Ref-1]:

Chemical substance	Annual Expected performance excluding contingency (kg)	Annual Maximum additional annual discharge (kg)
Boric acid (H_3BO_3)	2 000	7 000
Lithium hydroxide (LiOH)	Less than 1	4.4
Hydrazine (N_2H_4)	7	14
Morpholine (C_4H_9ON)	345	840
Ethanolamine (C_2H_7ON)	250	460
Nitrogen (expressed as N) excluding hydrazine, morpholine and ethanolamine	2 530	5 060
Phosphates (PO_4^{3-})	155	400
Detergents	650	1 600
Metals	16	27.5
Suspended solids	655	1 400
COD	1 490	2 525

Table 18: Expected performance excluding contingency and maximum annual additional discharge for chemicals associated with radioactive effluent

The impact of zinc acetate injection on liquid chemical discharges is considered negligible [Ref-4] (see PCSR Sub-chapter 5.5).

The table shows that for the EPR:

- boric acid: the proposed treatment of the primary water facilitates greater recycling. The use of boron enriched with boron-10 significantly reduces discharge in normal circumstances;

- morpholine: forms ethanolamine by thermal decomposition. This in turn, is decomposed in a series of reactions, finally forming glycolates, formiates, acetates and oxalates. The estimated maximum annual amount discharged for each of these substances is given in the following table [Ref-2] [Ref-3]:

	Acetates	Formiates	Glycolates	Oxalates
Annual amount	1.53	1.9	0.19	0.127

Table 19: Annual flux of the degradation products of morpholine and ethanolamine (in kg)

- nitrogen: nitrogen (excluding hydrazine, morpholine and ethanolamine) in the secondary circuit water is present only in the form of ammonium ions. When collected in the sumps and transferred to the storage tanks, it may be converted into nitrates (or possibly nitrites) on contact with atmospheric oxygen. In the environment, it is stable in the form of nitrates;

- because the discharge environment is seawater, the sodium level associated with phosphates is not specified: it is discharged in concentrations that are negligible compared with the concentration in the receiving environment;

- the distribution of all metals in the 0KER [LRMDS] and 0SEK [SiteLWDS] tanks, based on the proportions found in existing units, is as follows [Ref-3]:

Al	Cu	Cr	Fe	Mn	Ni	Pb	Zn
8.95%	0.70%	14.10%	59.30%	5.60%	0.75%	0.50%	10.10%

Table 20: Distribution spectrum for all metals

8.2. CHEMICAL DISCHARGES NOT ASSOCIATED WITH RADIOACTIVE EFFLUENT

The chemical discharges not associated with radioactive effluent will be site dependent. For the present phase of GDA, results developed for the Flamanville 3 reference plant are presented as an illustration [Ref-1].

Chemical discharges not associated with radioactive effluent arise from effluent generated from the conventional parts of the site, mainly:

- effluent from demineralised-water production (the main desalination unit and the supporting demineralisation station);

- effluent from biological fouling treatments (seawater chlorination).

- Water collected from rainwater drains and black and grey wastewater (effluent from the purification stations);

- water contaminated with oil, and water used in production in the Turbine Hall.

8.2.1. Chemical effluent from the demineralisation station and desalination unit

The demineralisation station and desalination unit discharge iron, total suspended solids, chlorides, sodium, sulphates, detergents and brine.

The maximum annual amounts of discharged chemicals resulting from supplying the EPR unit are shown below. They are calculated assuming that the desalination unit runs continuously, that pre-processing in the current demineralisation unit runs for several hours per day and that the regeneration cycles operate for 40 days per year.

Substance	Maximum Annual Additional Discharge (kg)
Chlorides	3 616
Sulphates	11 725
Sodium	13 523
Suspended solid	1 621
Iron	848
Detergents	312

Table 21: Maximum amounts discharged during the production of demineralised water for the EPR unit

Brine is discharged into the intake channel at a rate of 150 m^3/h at a concentration of 70 g/litre.

8.2.2. Discharge of black and grey wastewater, water contaminated with oil and rainwater

Chemicals discharged into the sea from the sewage network are treated in the purification station. This treatment ensures that the BOD_5 (5-day biological oxygen demand) of the discharged effluent is less than 35 mg/litre.

Waste water that could contain hydrocarbons is treated in the on-site oil filters. The hydrocarbon concentration in the discharged water is below 5 mg/litre.

8.2.3. Discharge from anti-fouling treatments

Chlorination is carried out once the temperature of the seawater reaches 10°C. The process involves discharging both residual oxidants into the sea (both in the free state and as chlorine compounds) and trihalomethanes (as bromoform). Chlorides from cleaning the processing equipment are also discharged into the sea:

- normal chlorination: The standard processing method is chlorination using a concentration of 0.5 mg/litre of active chlorine. Injection is sequential, once every 30 minutes per cooling channel;

- exceptional cases: A change in the water quality may cause excessive biological fouling, requiring exceptional chlorination at 1 mg/litre (10 days each year, non-consecutive) to treat the various sections of the service-water circuits.

In addition, shock chlorination at 6 mg/litre may be applied to the SEN, SEC [ESWS], and SRU [UCWS] circuits, which have piping taking top-up water from the Pumping Station, with a number of dead areas, very likely to develop biological fouling.

Realistic values for the expected discharge from the EPR unit, based on experience of the two production units operating at Flamanville, are shown in the table below.

	Residual oxidants	Bromoform
Chlorination	0.14	0.0027

Table 22: Realistic concentration in the outfall structure (mg/litre)

This table presents the expected performance excluding contingencies for the chemicals from electrochlorination.

A change in the water quality may cause excessive biological fouling, requiring exceptional chlorination at 1 mg/litre (10 days each year, non-consecutive) to treat the various sections of the service water circuits.

The estimated discharge from treating circuits against biological fouling is as follows:

	Maximum concentration in the outfall structure (mg/litre)	
	Residual oxidants	Bromoform
Normal chlorination	0.5	0.02
Exceptional chlorination, at 1 mg/litre	1	0.04
Shock chlorination at 6 mg/litre	0.72	0.0244

Table 23: Oxidant and bromoform discharge from the EPR unit

The annual mass of discharged chlorides is estimated at 2600 kg.

9. CONCLUSION

Research into improving the environmental performance of the EPR facility, compared to units currently in operation, has been conducted and has led to the following significant advances:

- **reduced use of natural uranium resources, a significant reduction in the long lived radioactive waste** produced by the fuel and its cladding, and a better in-situ use of plutonium (-15% by in-situ burnup). These gains arise from neutronics design (including a large core and a neutron reflector) and higher fuel burnup;

- **significantly less liquid radioactive waste (with the exception of tritium and carbon-14) is expected** than that of the current fleet mainly due to the recycling of aerated primary effluent and to better selective sorting of the floor drains, and to a reduction in the source terms of cobalt-58 and cobalt-60 following the optimisation of primary coolant chemical treatment and, where possible, the use of material without cobalt;

- **significantly less gaseous radioactive waste (with the exception of tritium and carbon-14) is expected** than that of the current fleet due to the Gaseous Effluent Treatment System (TEG [GWPS]) operating in an almost closed loop and treating aerated gaseous waste;

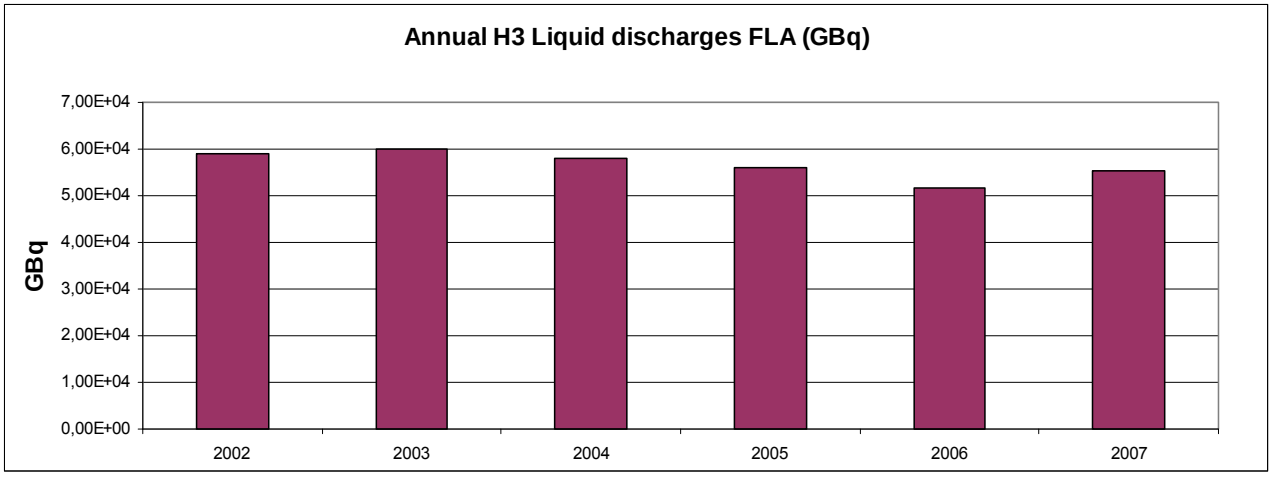
- **increased control of the production of tritium,** despite the change to high burnup fuel management through optimisation of the boron and lithium concentration by using enriched boron and increasing the number of gadolinium rods, etc., to achieve a specific output (calculated per kWh produced) of tritium almost equal to, or lower than that of the French existing units. Carbon-14 production depends on the size of the core, thus the EPR C-14 expected discharge performance is proportionally higher than that of the French existing units;

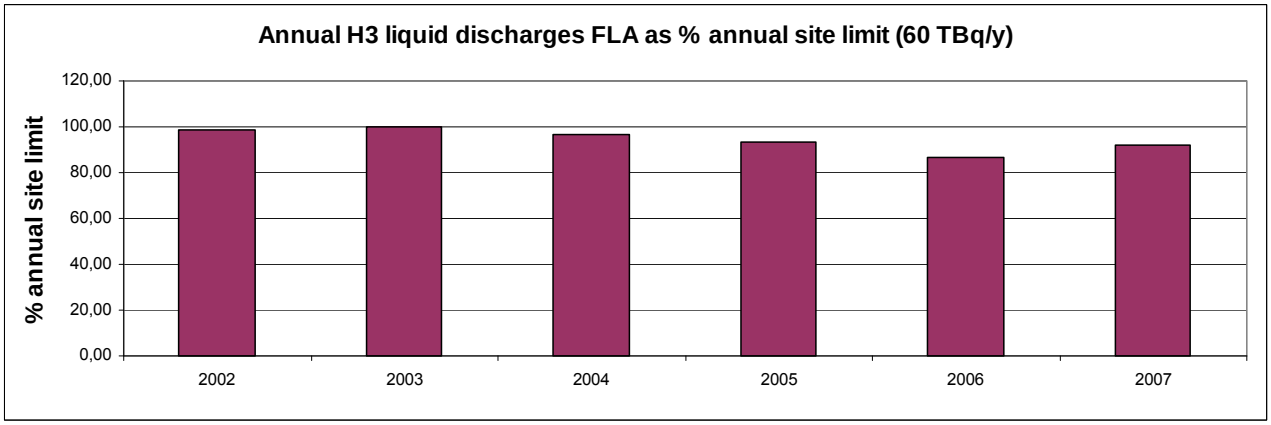
- **significant reduction in some types of chemical waste**, in particular discharges of boron from increased recycling and lower initial boron concentration in the primary cooling system water, due to the use of enriched boron, of hydrazine by inclusion of measures allowing its destruction before discharge, and of phosphates with hold-down devices on the systems using phosphate for treatment.

Also, discharges during normal operation, excluding contingency, from the EPR are systematically lower than, or equal to, those of a 1300 MW(e) unit with the exception of tritium and carbon-14, taking the 1st quartile from recent operating experience feedback as a reference, and for up to 33% more energy produced due to the combined effects of greater installed power and very high availability.

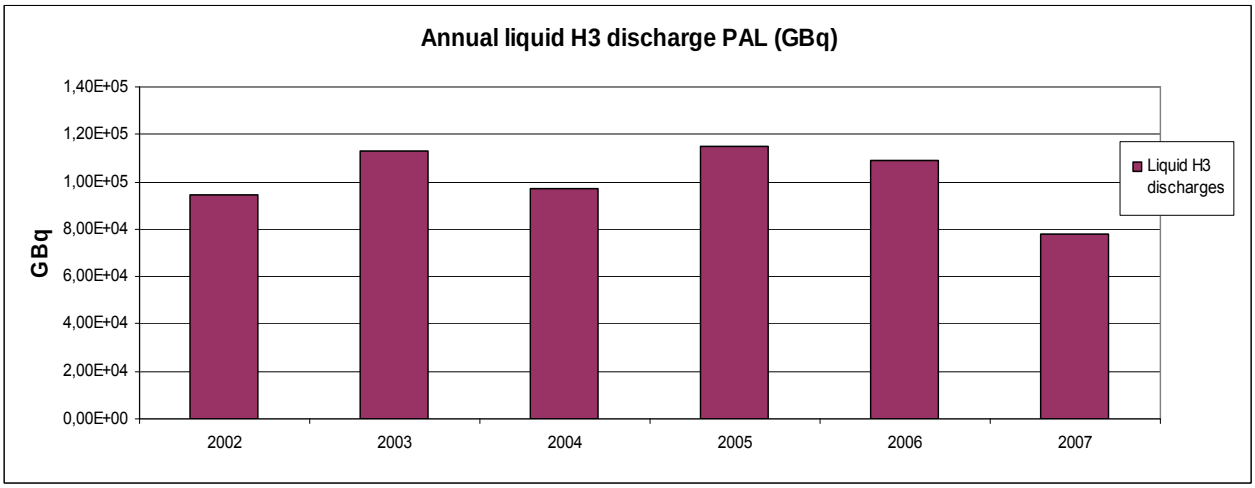
It should however be noted that the estimated values depend on the balance between discharge and waste and may, therefore, change according to the effluent treatment methods which will be used.

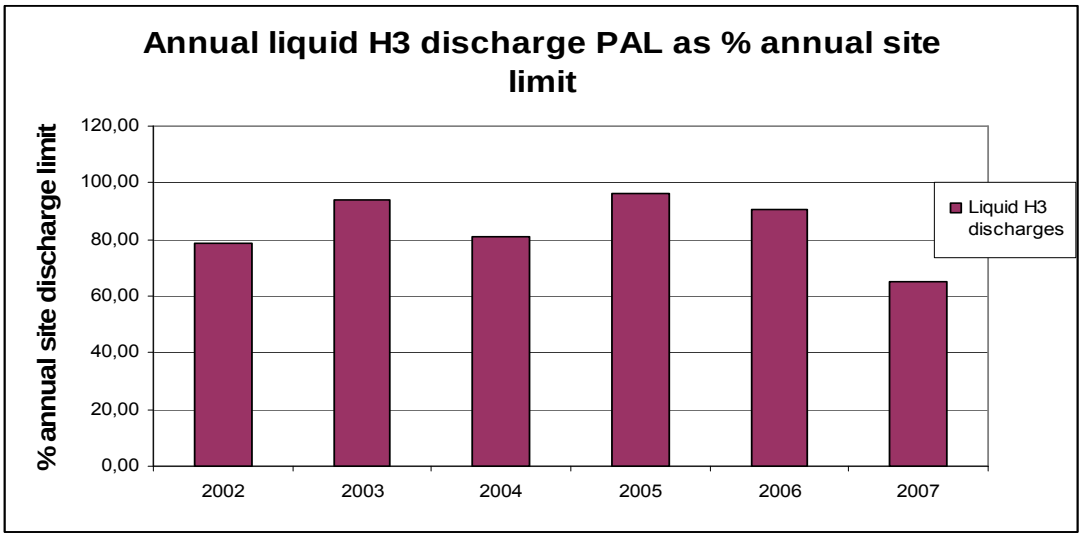
Appendix A-1: Annual site discharge liquid tritium (H-3) Flamanville, total activity (GBq) and as percentage of the annual site discharge limit



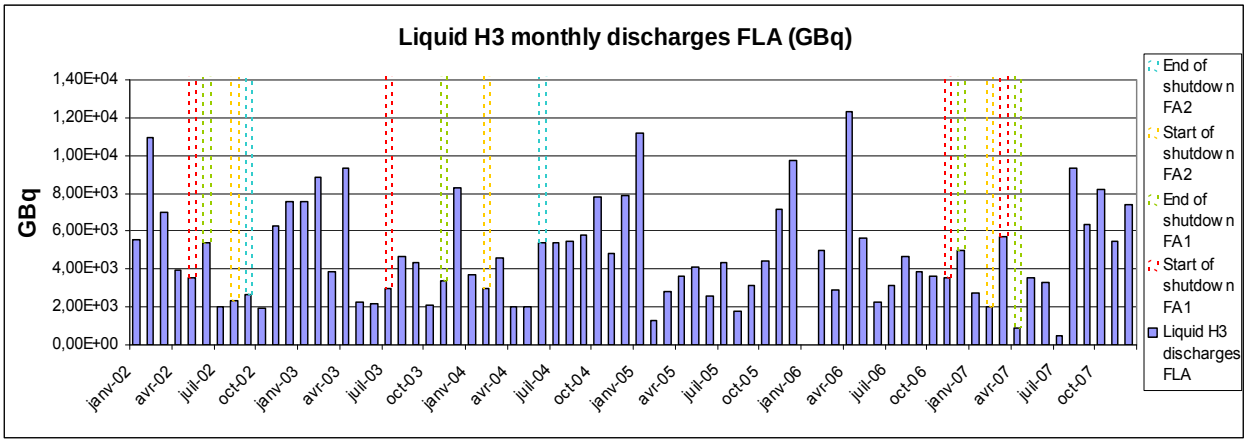


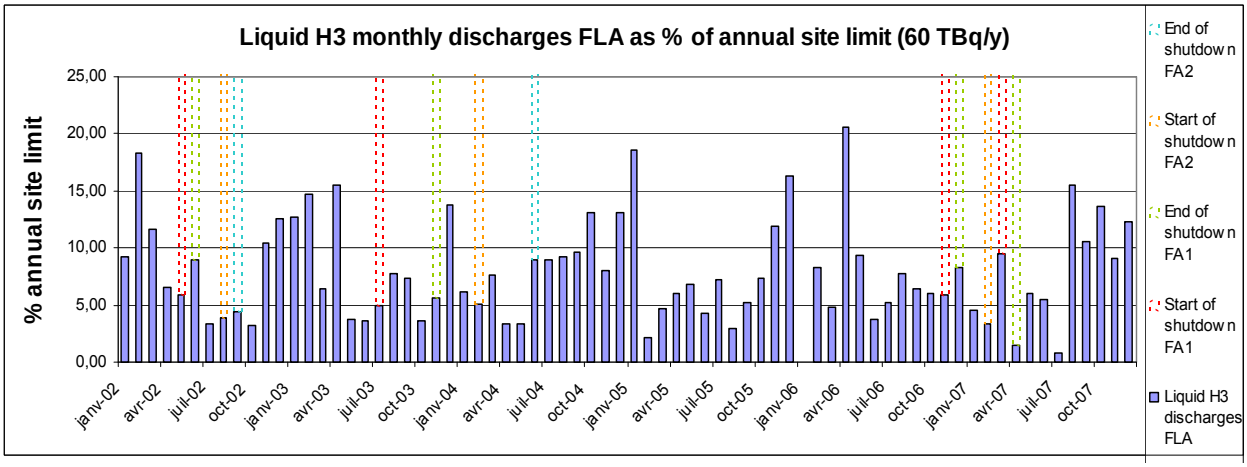
Appendix A-2: Annual site discharge liquid tritium (H-3) Paluel, total activity (GBq) and as percentage of the annual site discharge limit.

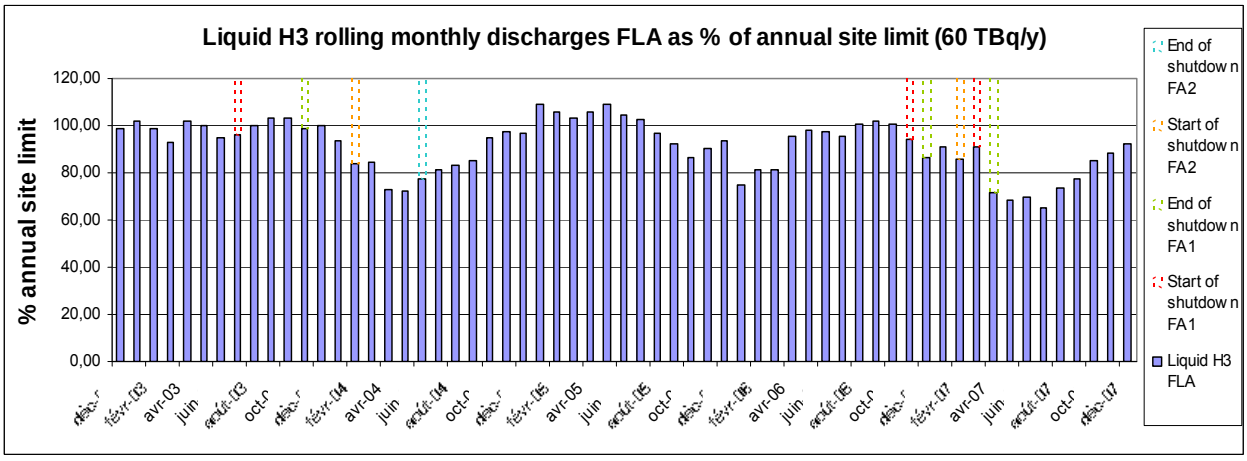




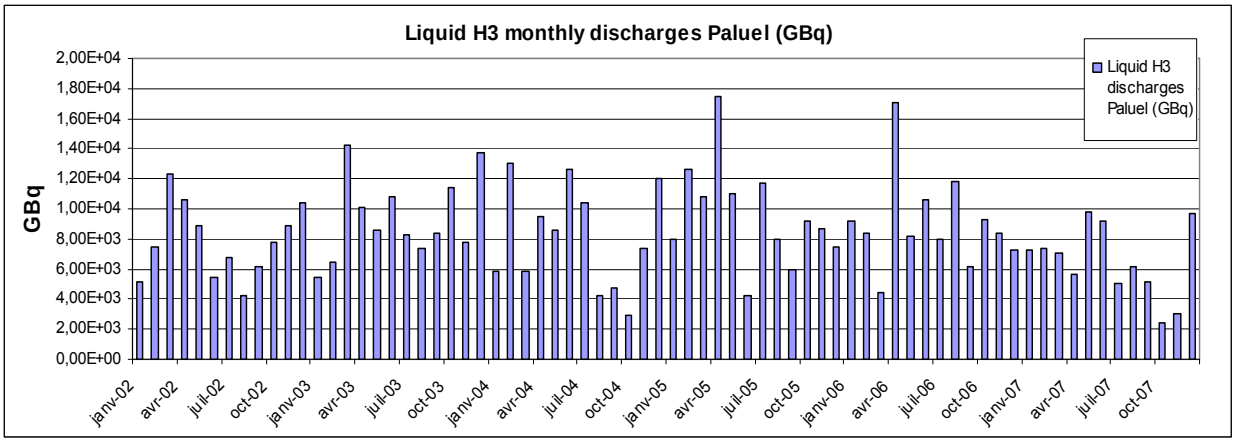
Appendix A-3: Monthly and rolling monthly discharges liquid tritium (H-3) Flamanville, total activity (GBq) and as percentage of annual site discharge limit.

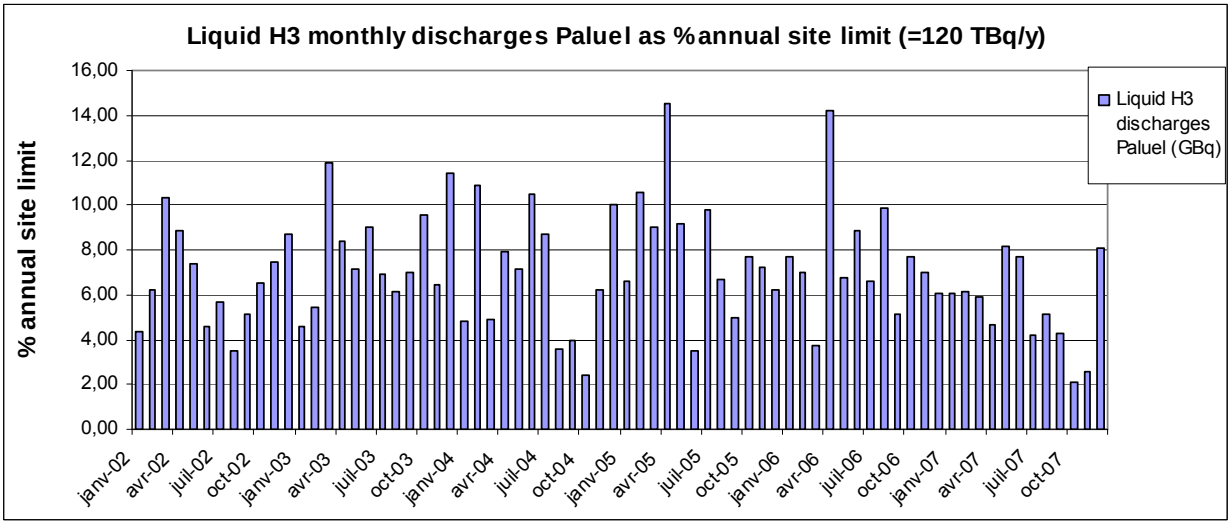


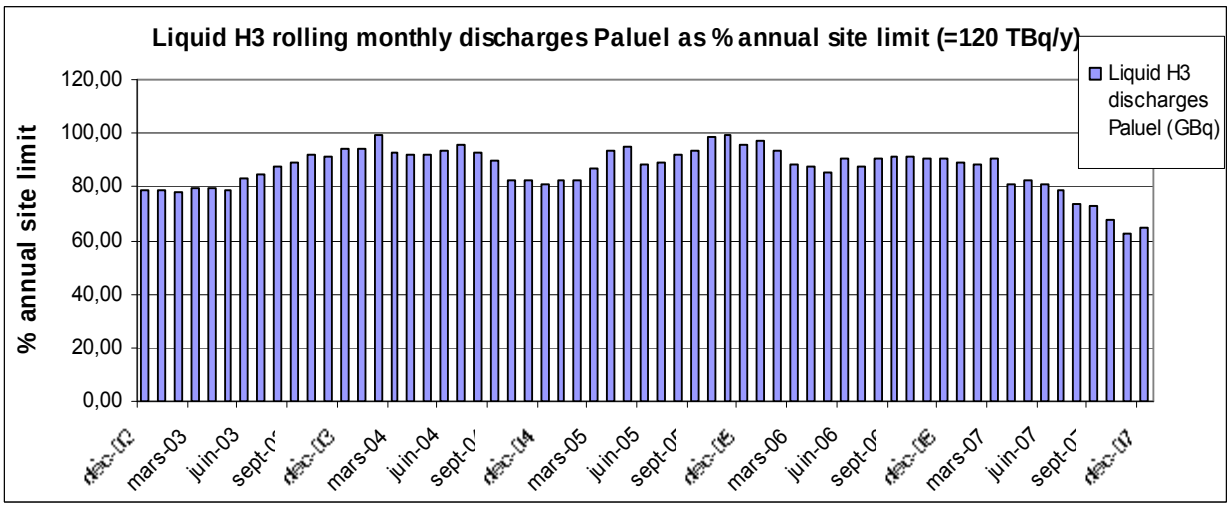




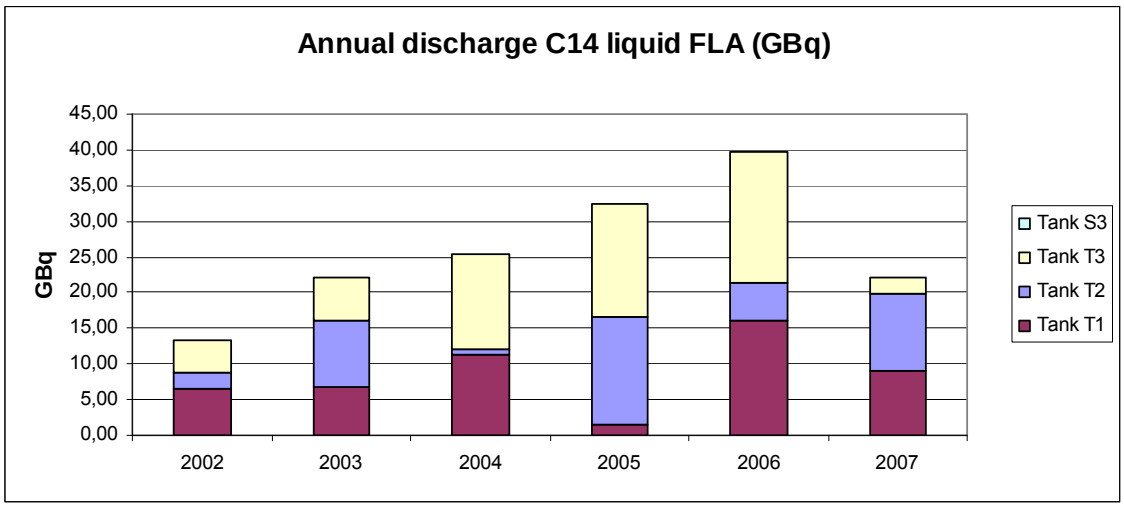
Appendix A-4: Monthly and rolling monthly discharges liquid tritium (H-3) Paluel, total activity (GBq) and as percentage of annual site discharge limit.

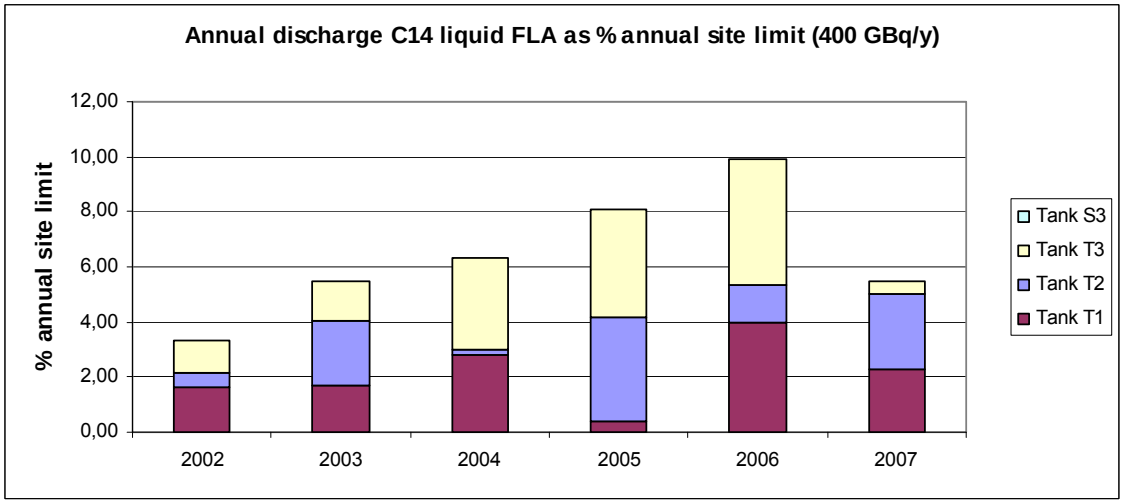




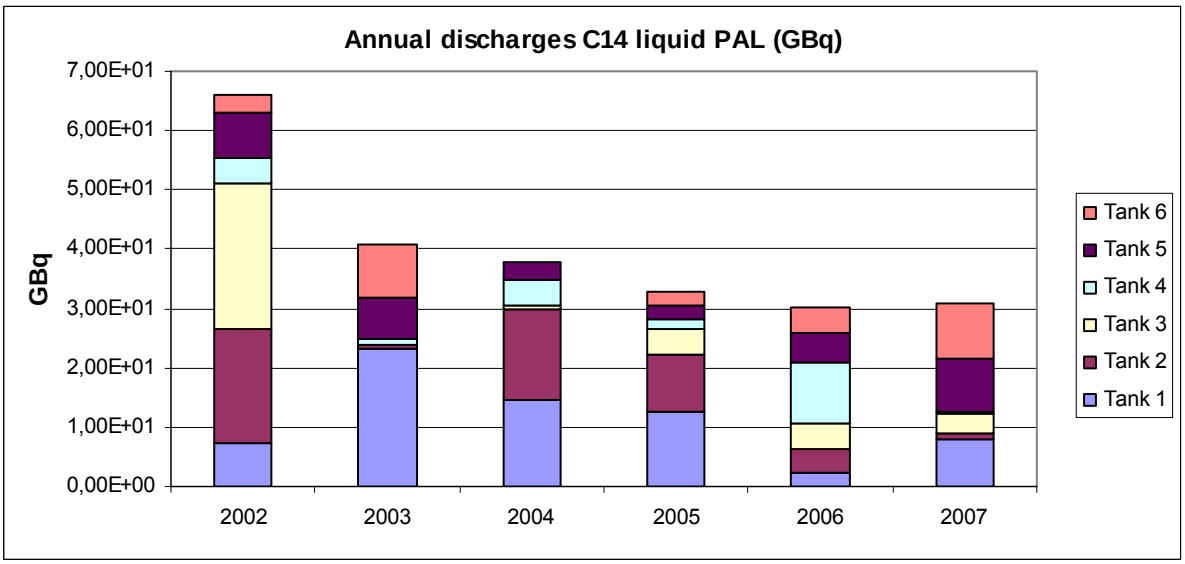


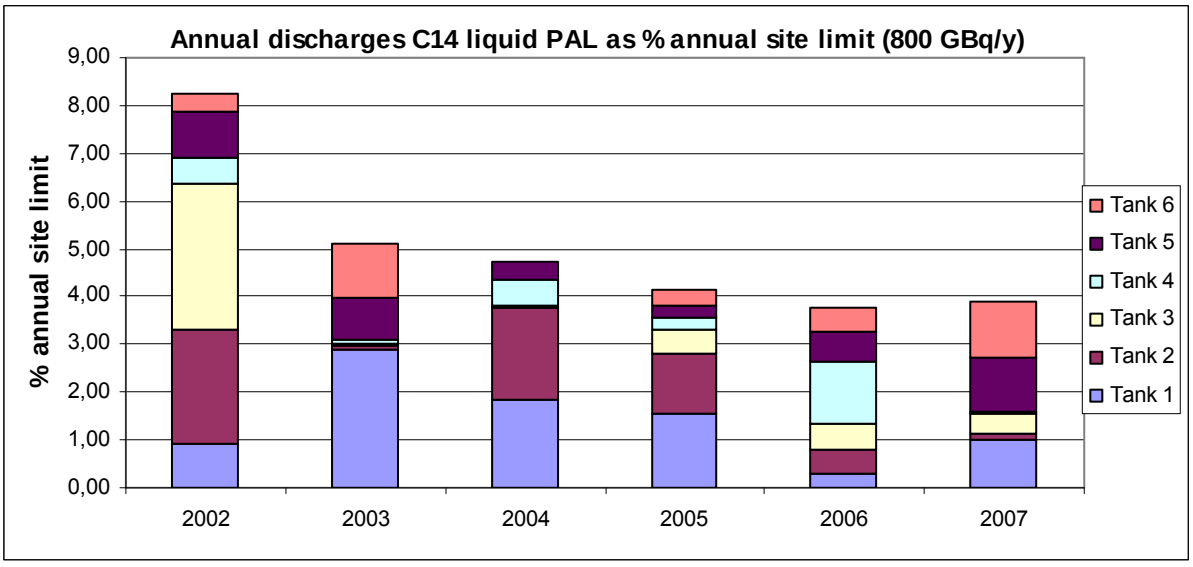
Appendix A-5: Annual site discharge C-14 liquid Flamanville, total activity (GBq) and as percentage of the annual site discharge limit.



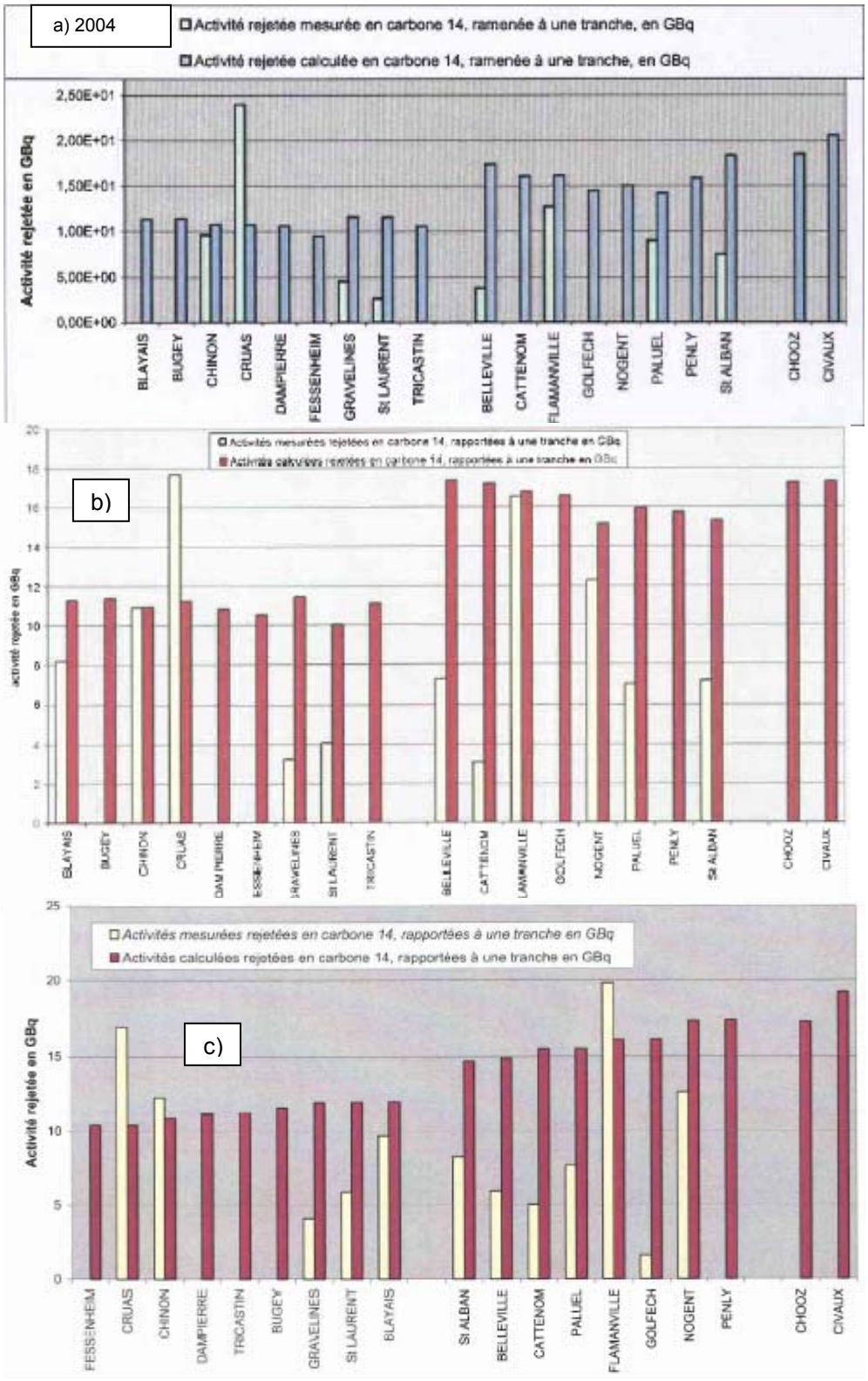


Appendix A-6: Annual site discharge C-14 liquid Paluel, total activity (GBq) and as percentage of the annual site discharge limit.

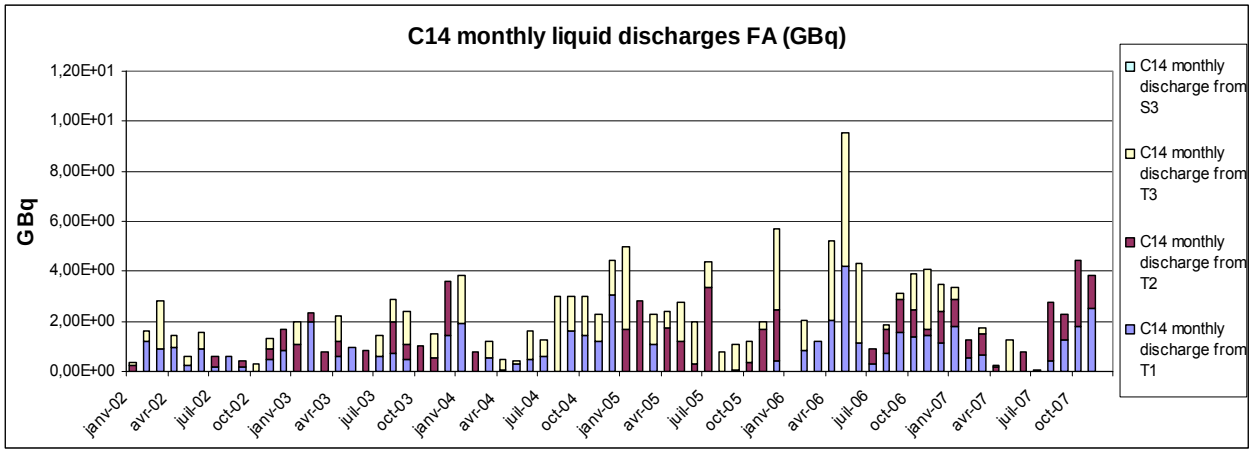


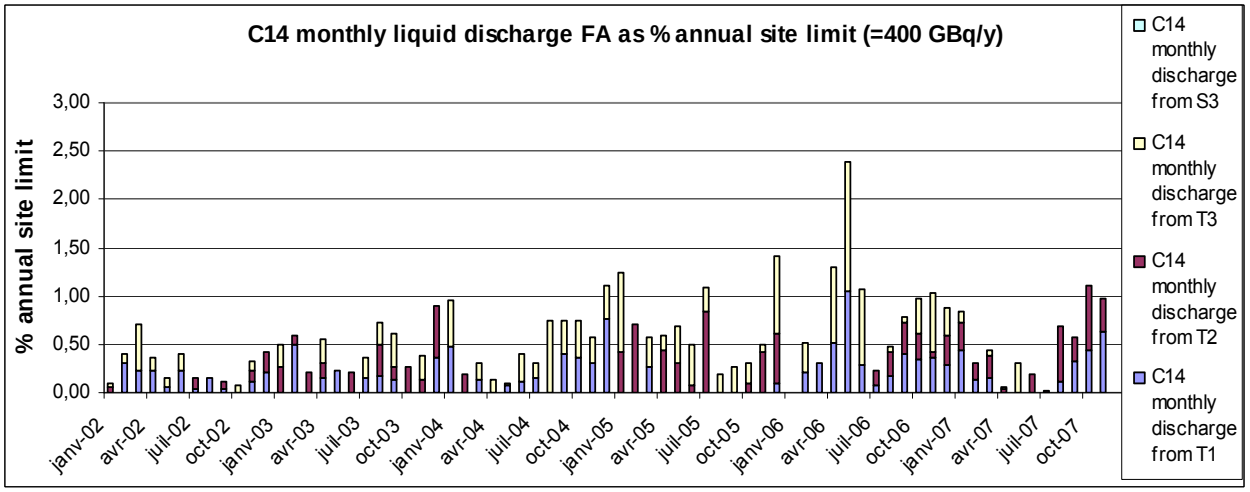


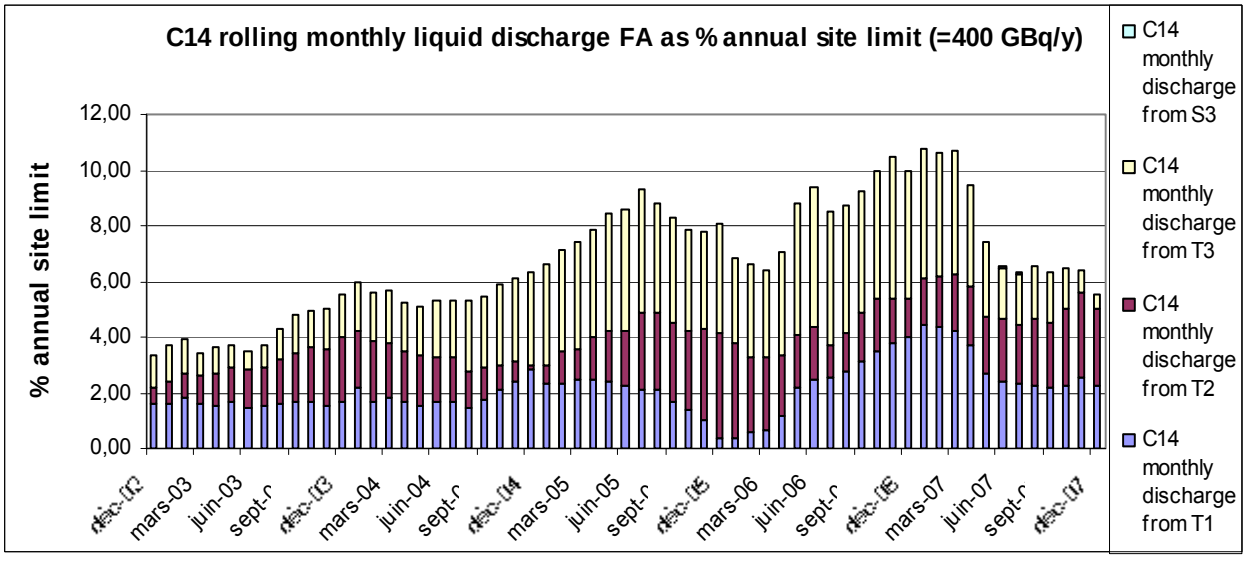
Appendix A-7: Liquid C-14 Annual Activity (discharged and calculated) in GBq per unit for a) 2004, b) 2005 and c) 2006



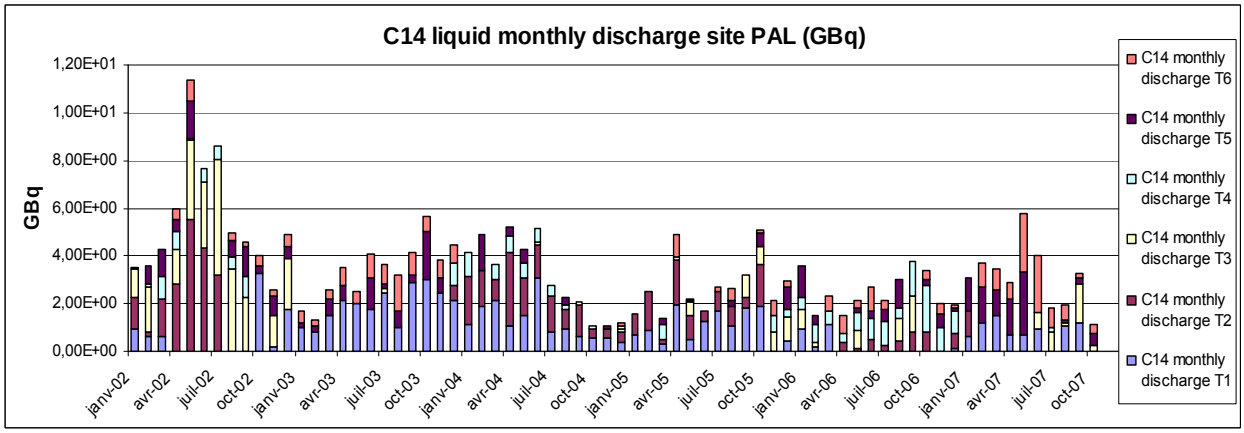
Appendix A-8: Monthly and rolling monthly discharges C-14 liquid Flamanville, total activity (GBq) and as percentage of the annual site discharge limit.

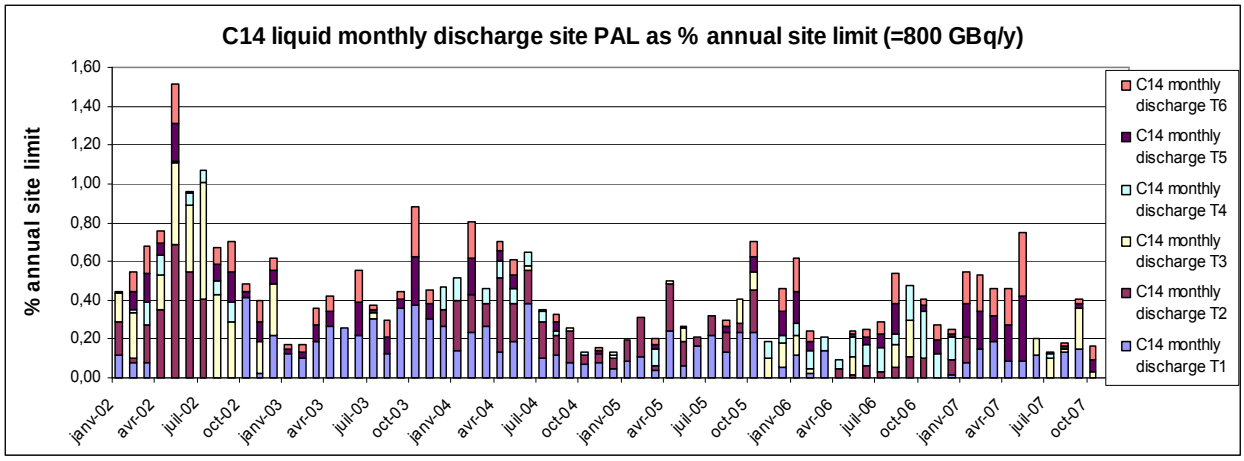


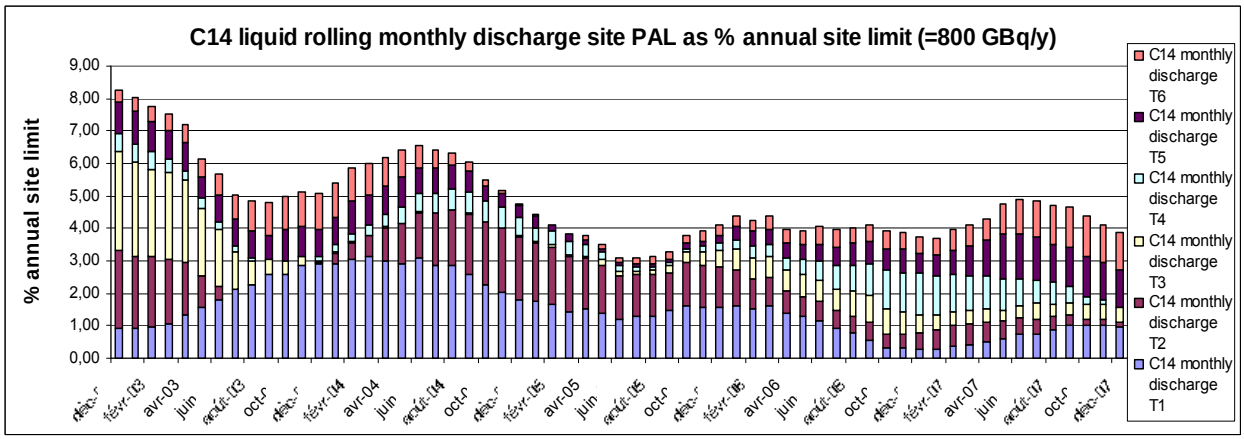




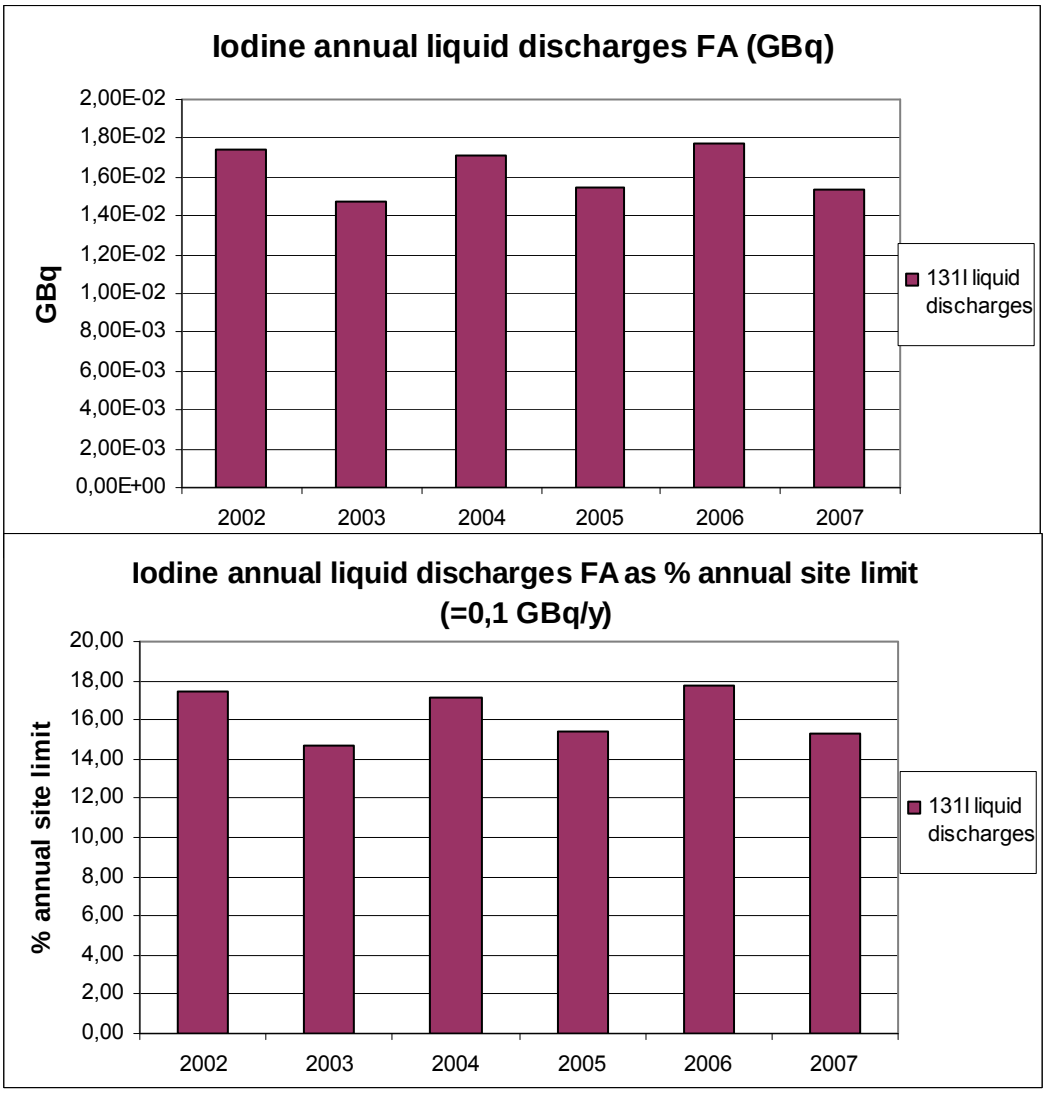
Appendix A-9: Monthly and rolling monthly discharges C-14 liquid Paluel, total activity (GBq) and as percentage of the annual site discharge limit.



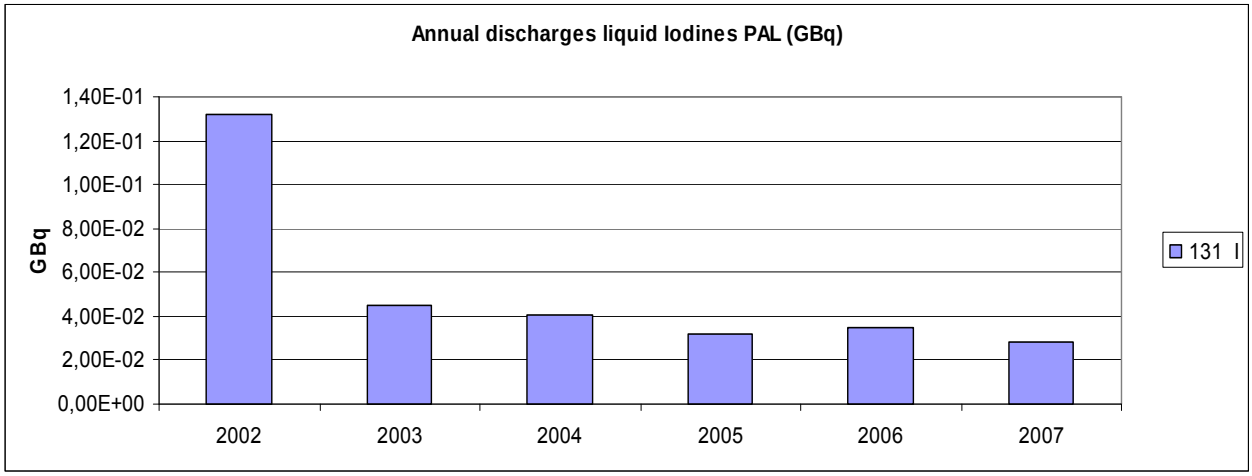


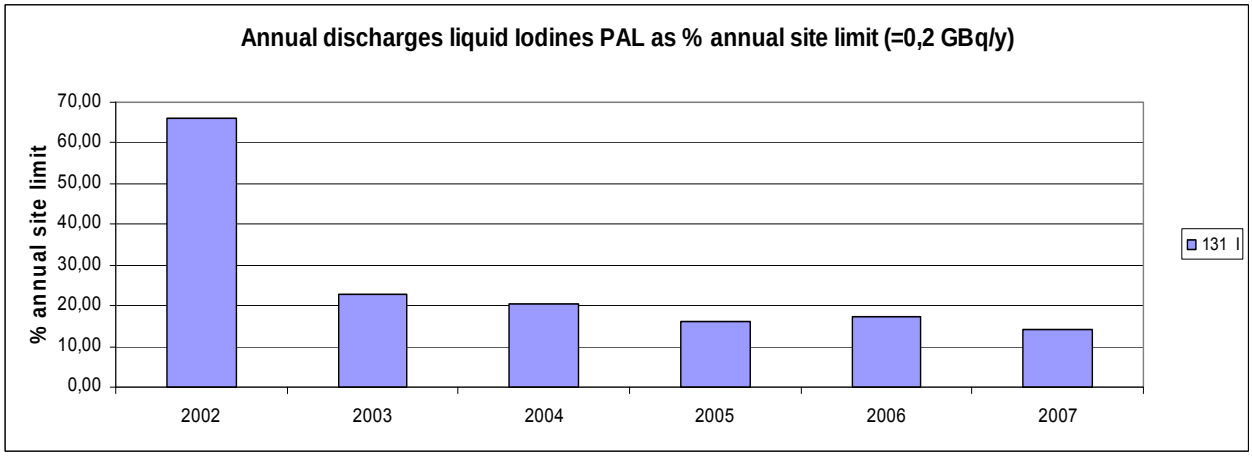


Appendix A-10: Annual discharges liquid Iodine Flamanville, total activity (GBq) and as percentage of annual site discharge limit.

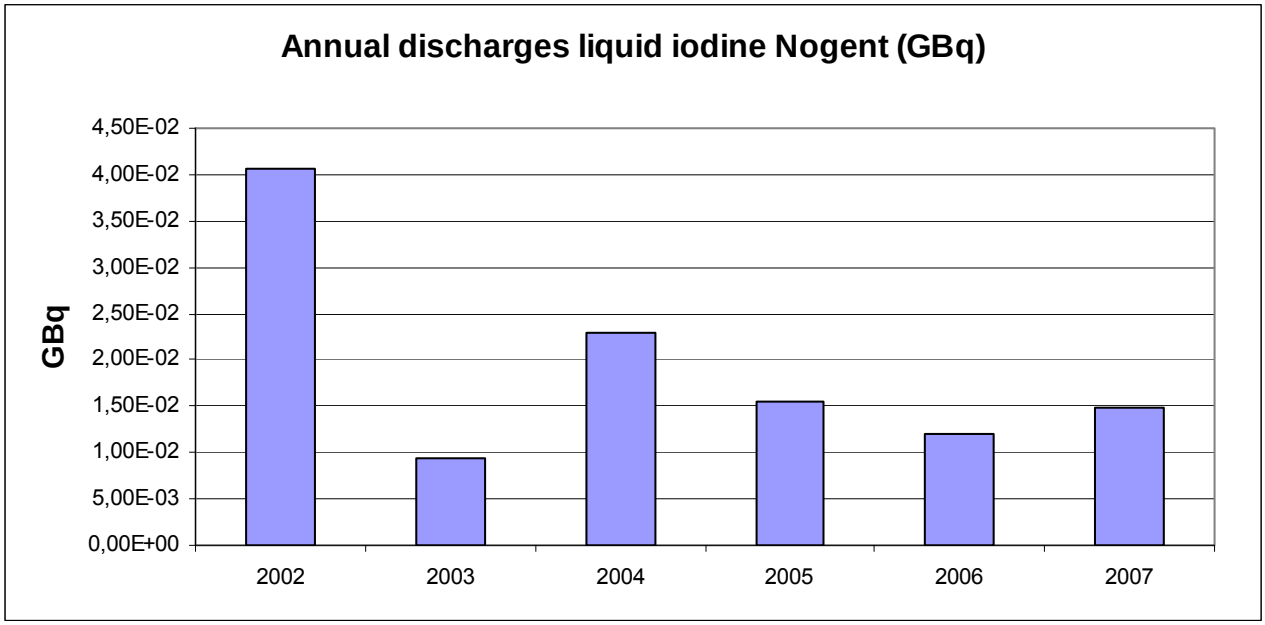


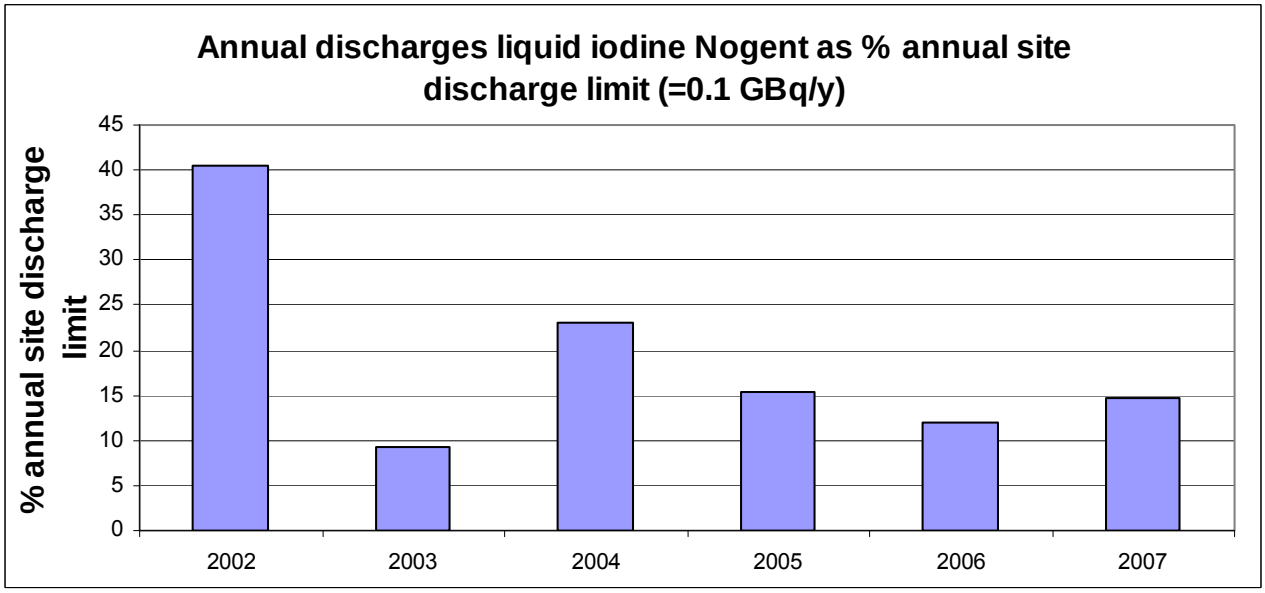
Appendix A-11: Annual discharges liquid Iodine Paluel, total activity (GBq) and as percentage of annual site discharge limit.



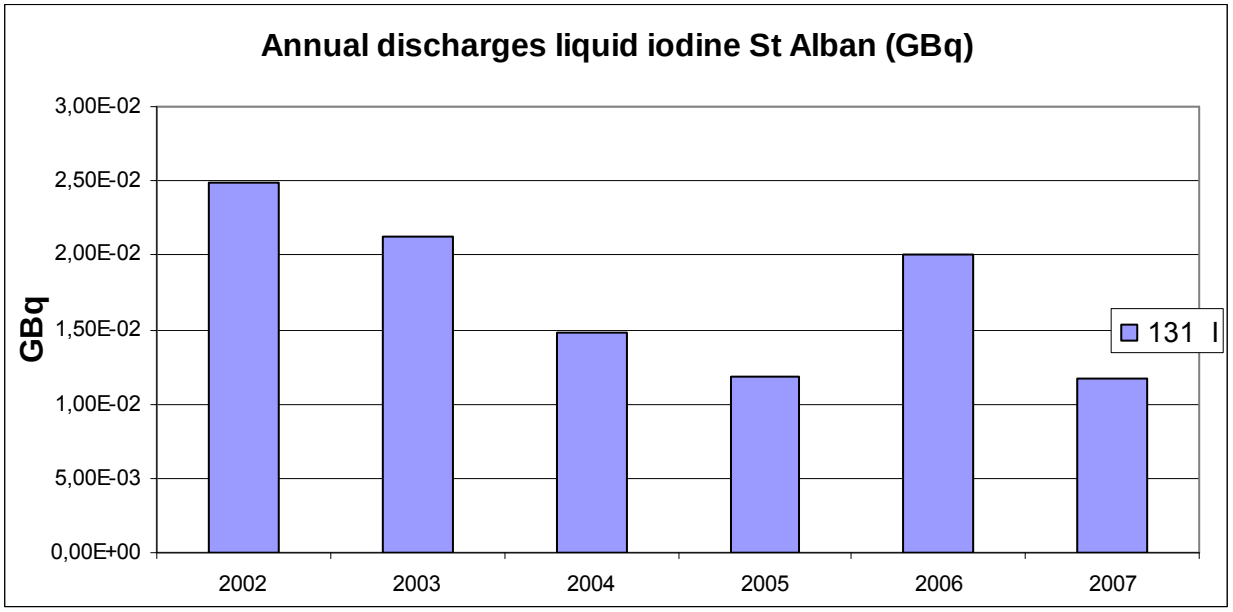


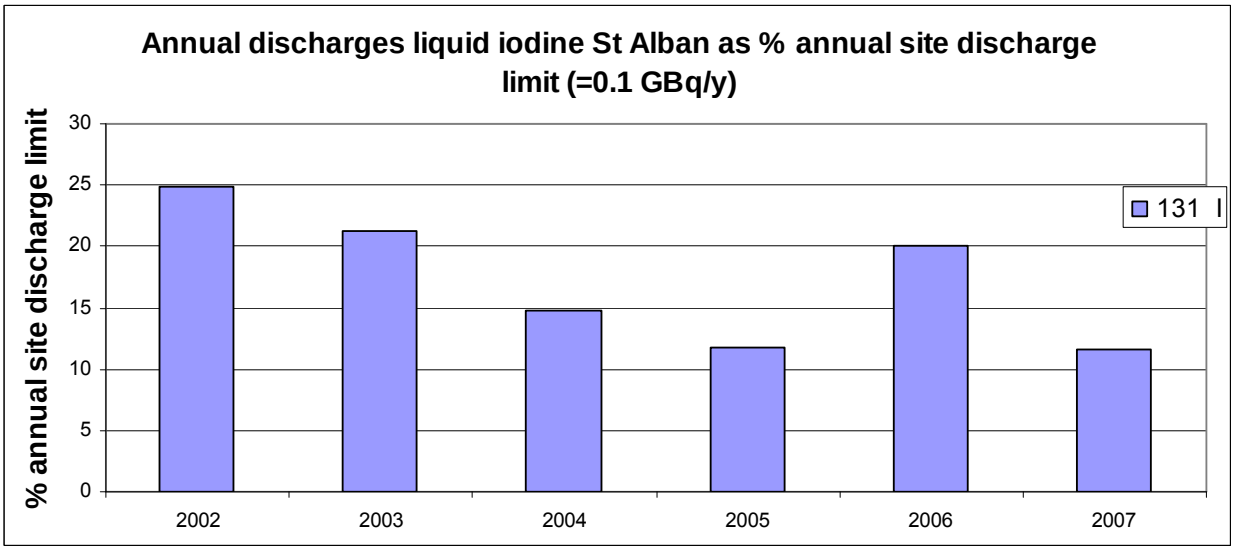
Appendix A-12: Annual discharges liquid Iodine Nogent, total activity (GBq) and as percentage of annual site discharge limit.



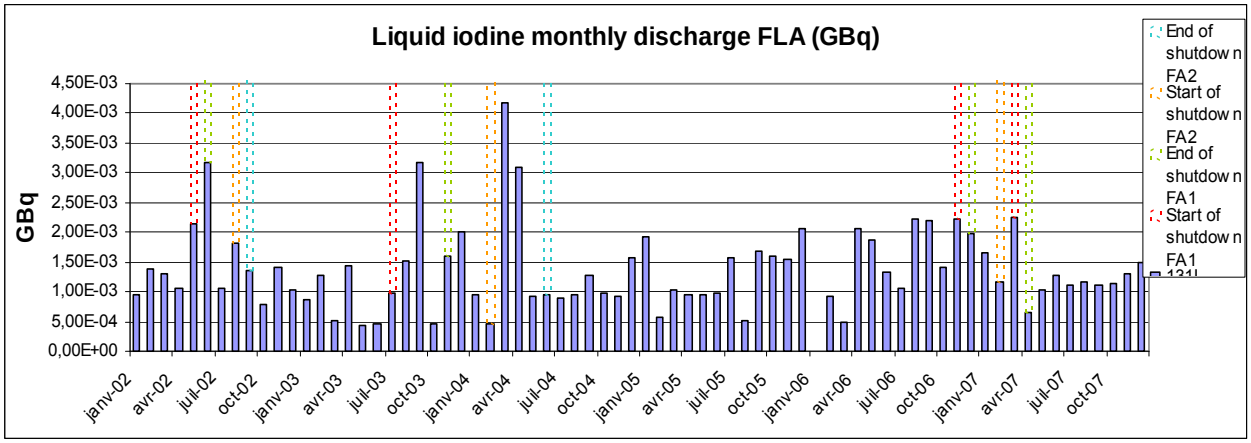


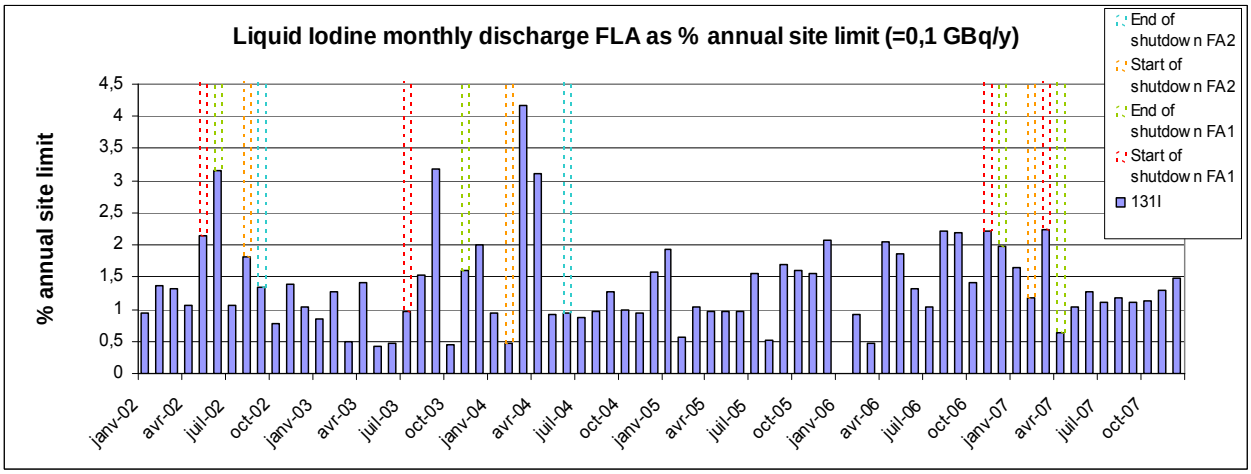
Appendix A-13: Annual discharges liquid Iodine St Alban, total activity (GBq) and as percentage of annual site discharge limit.

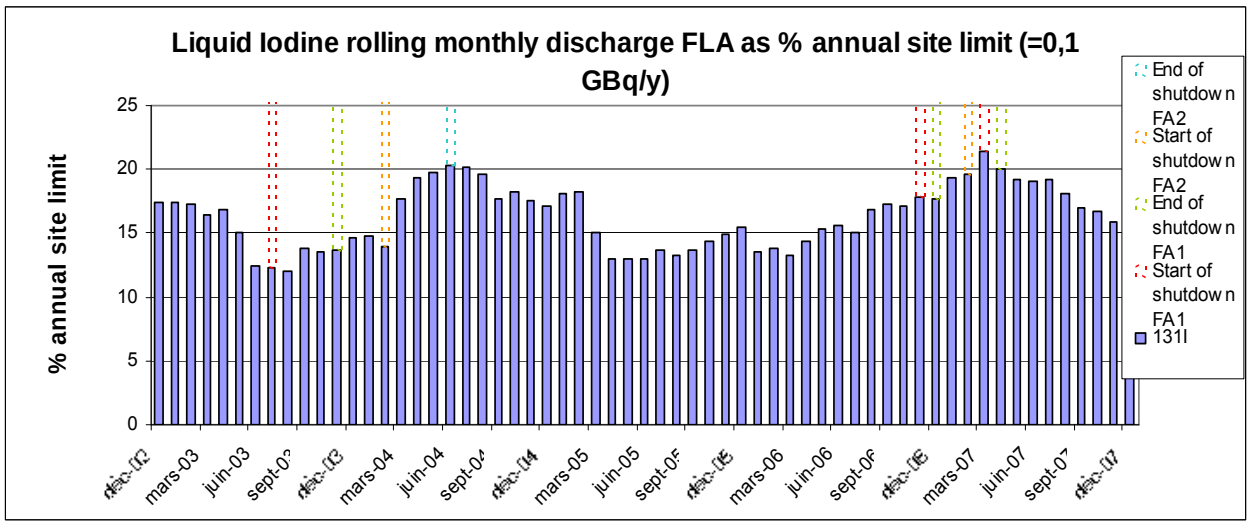




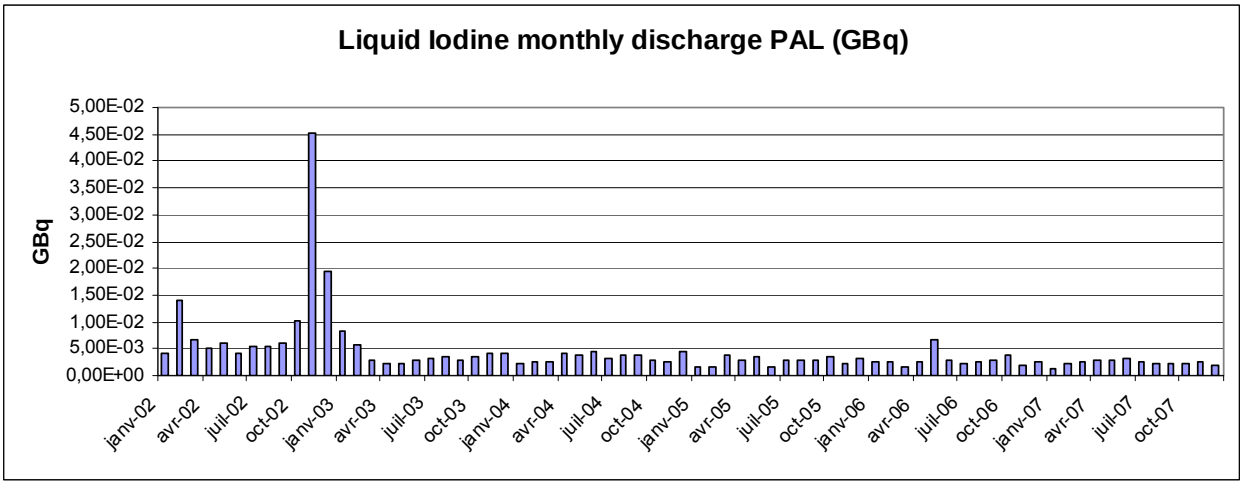
Appendix A-14: Monthly and rolling monthly discharges liquid Iodine Flamanville, total activity (GBq) and as percentage of annual site discharge limit.

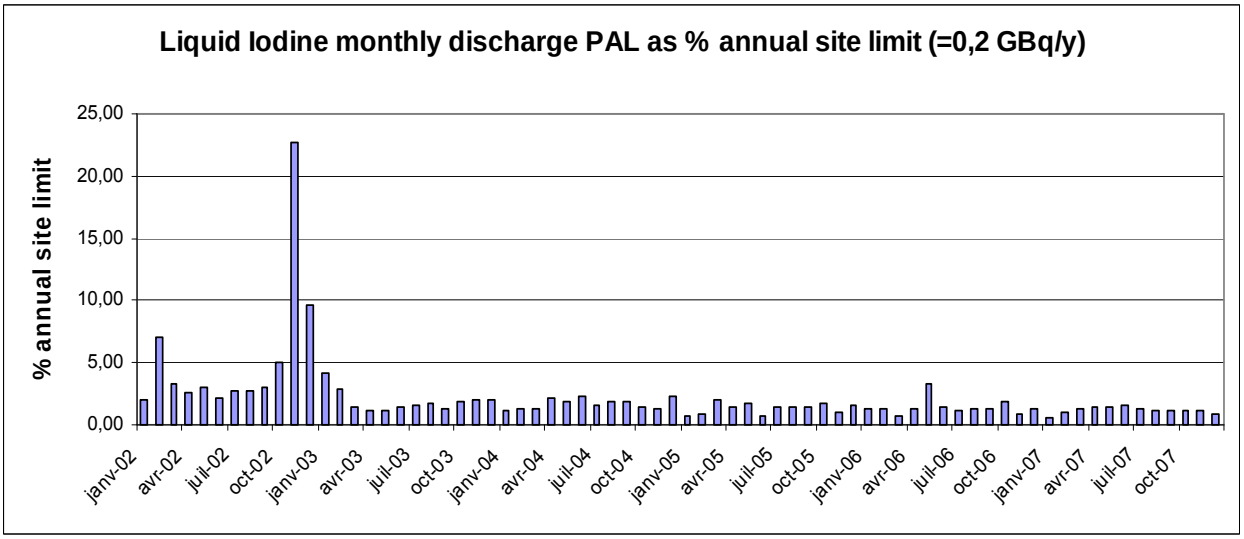


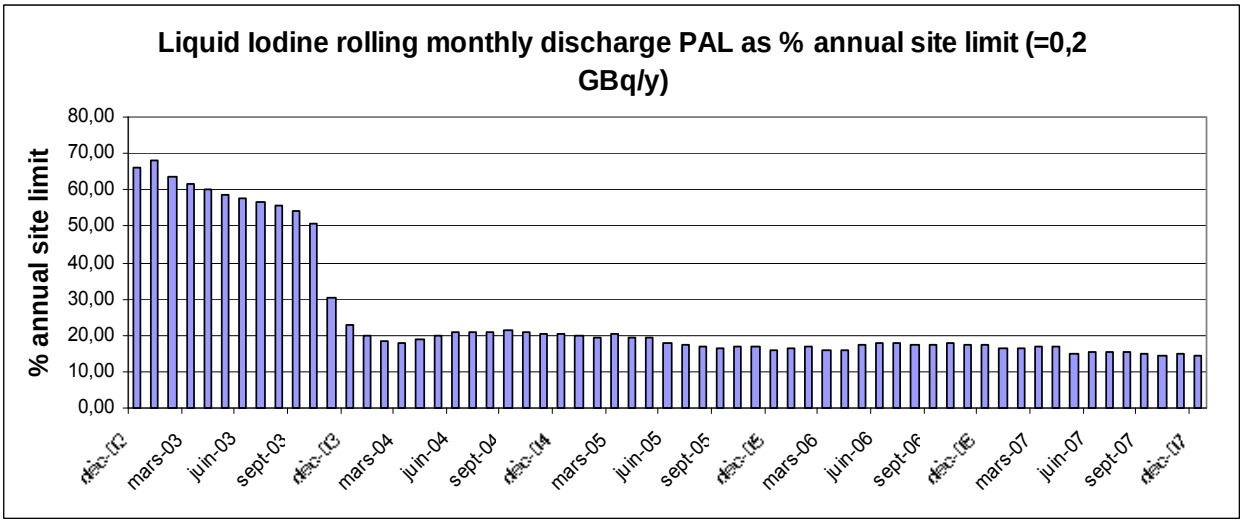




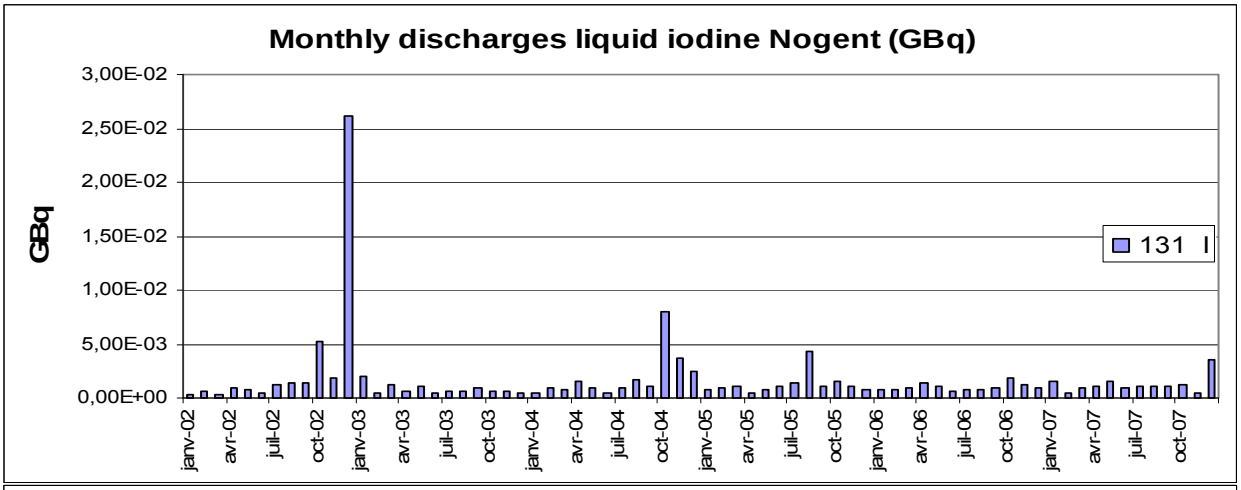
Appendix A-15: Monthly and rolling monthly discharges Iodine liquid Paluel, total activity (GBq) and as percentage of the annual site discharge limit.

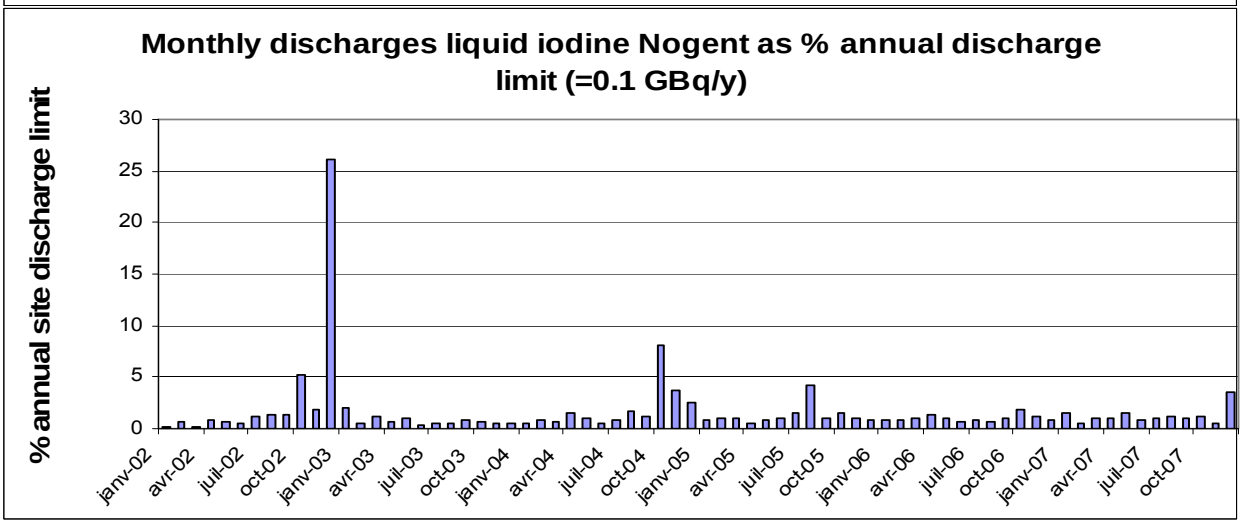


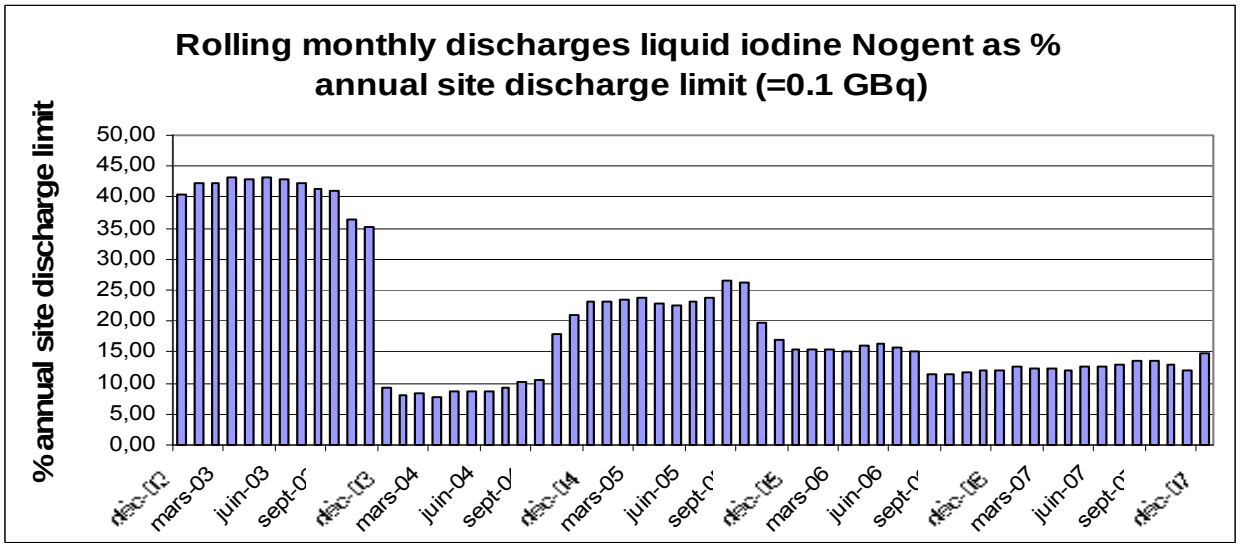




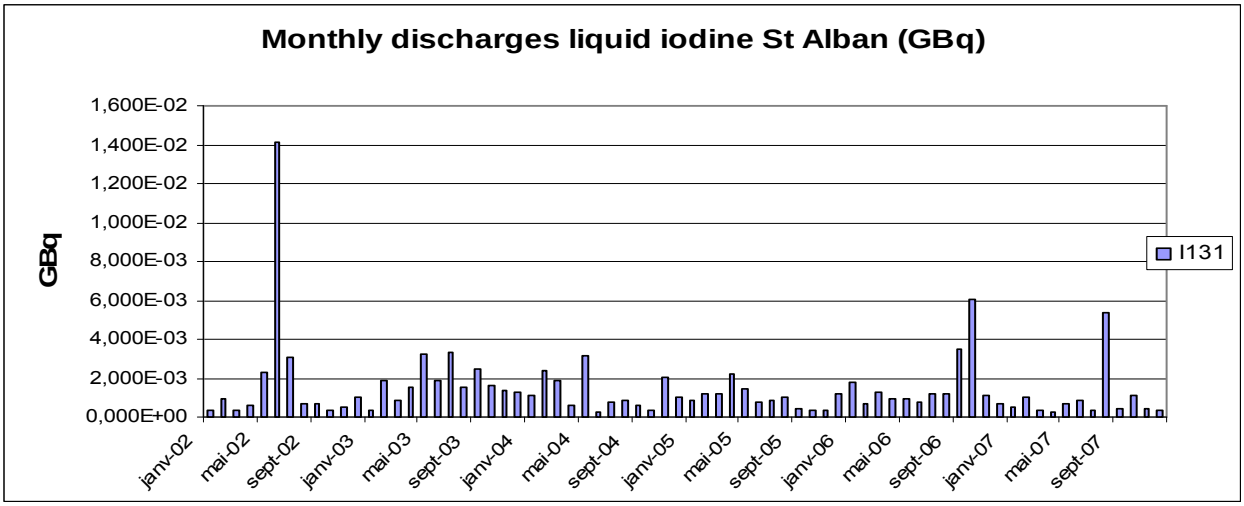
Appendix A-16: Monthly and rolling monthly discharges Iodine liquid Nogent, total activity (GBq) and as percentage of the annual site discharge limit.

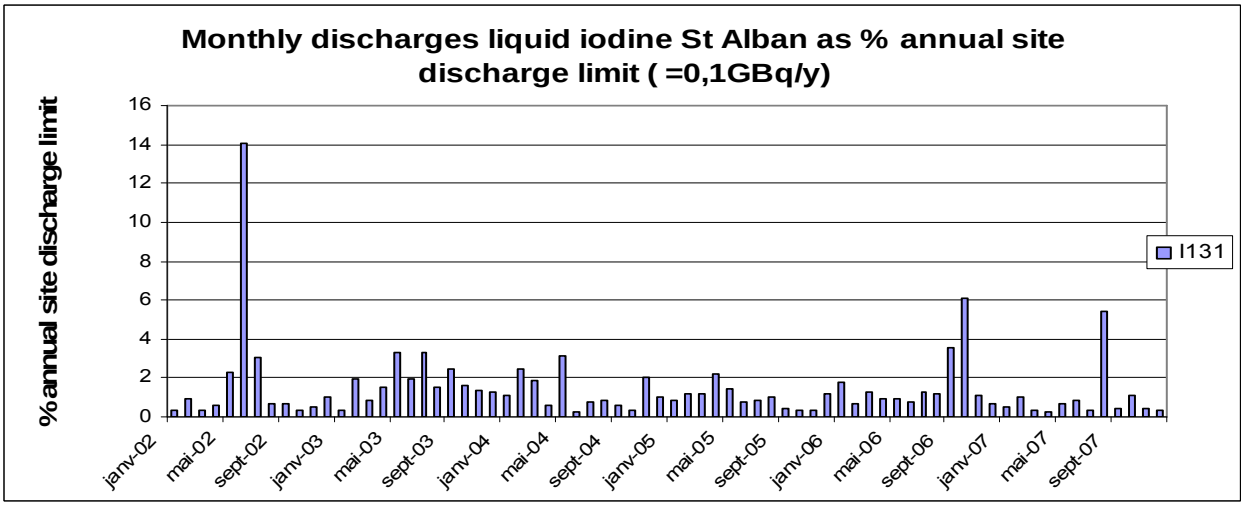


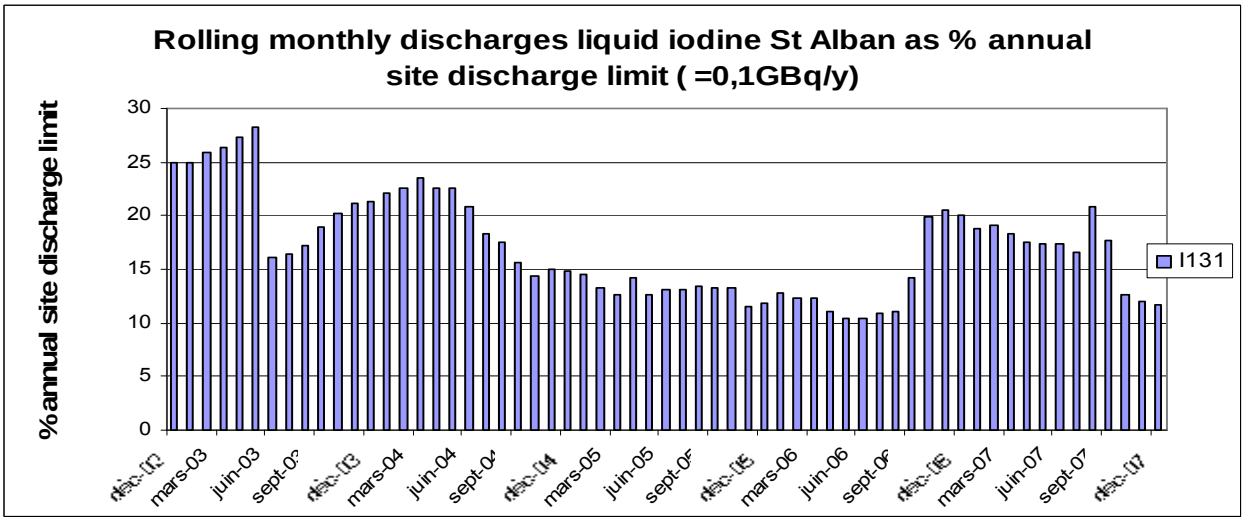




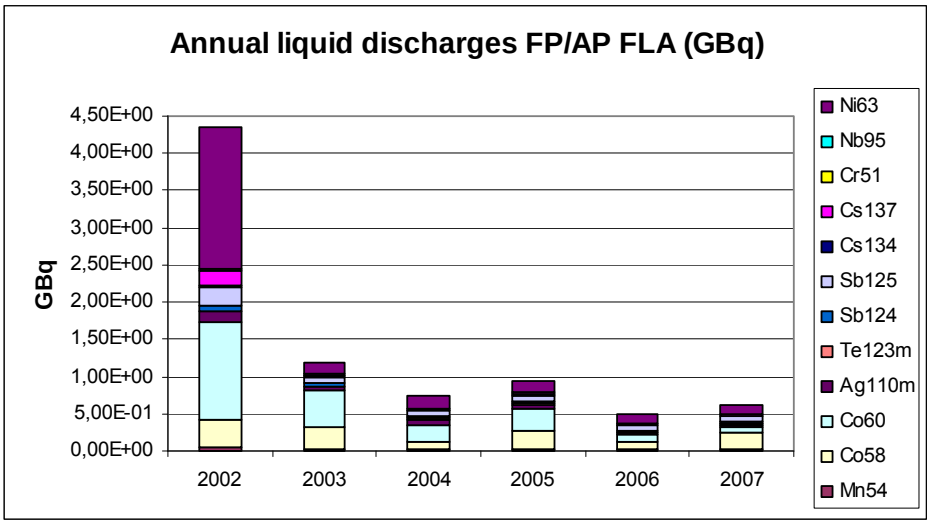
Appendix A-17: Monthly and rolling monthly discharges Iodine liquid St Alban, total activity (GBq) and as percentage of the annual site discharge limit.

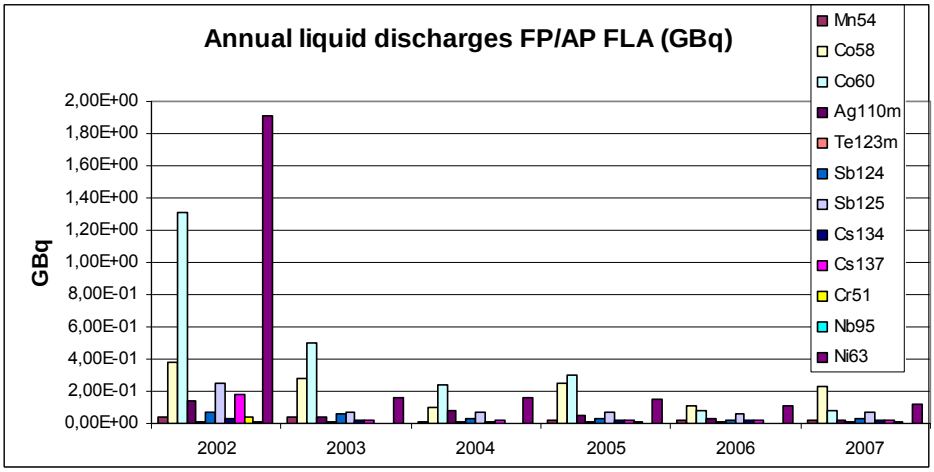


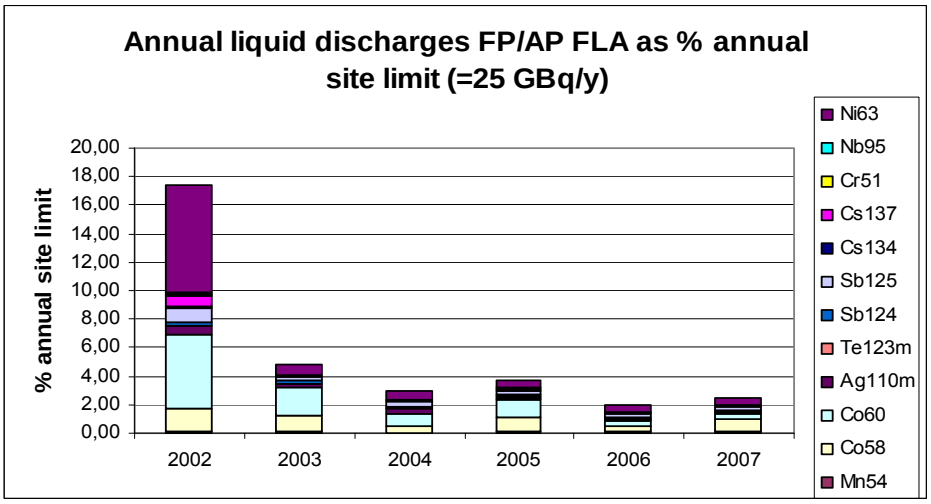




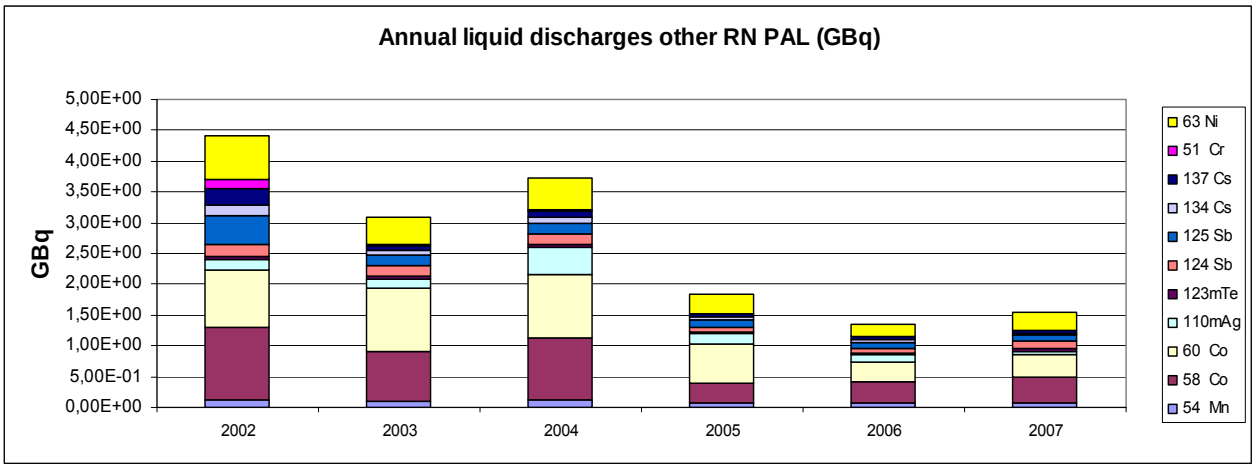
Appendix A-18: Annual discharges other radionuclides liquid Flamanville, total activity (GBq) and as percentage of annual site discharge limit.

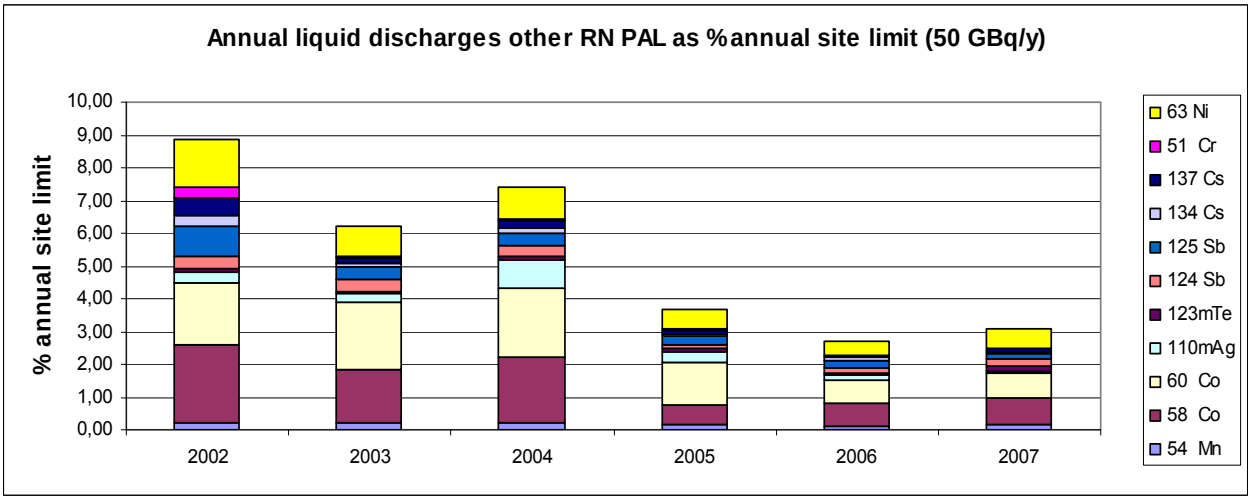




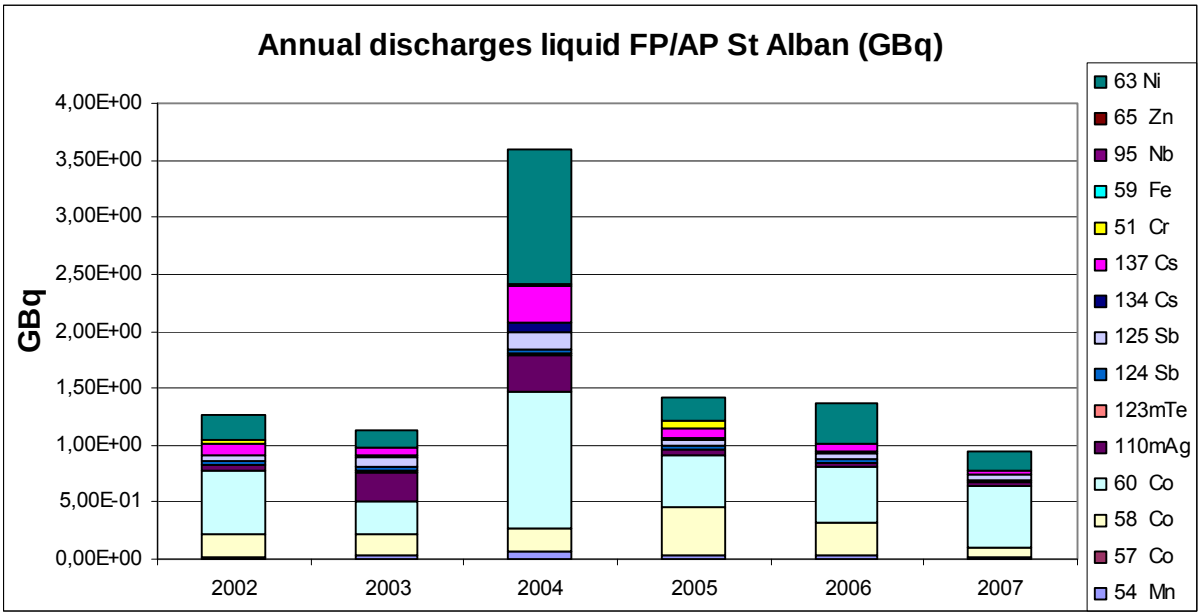


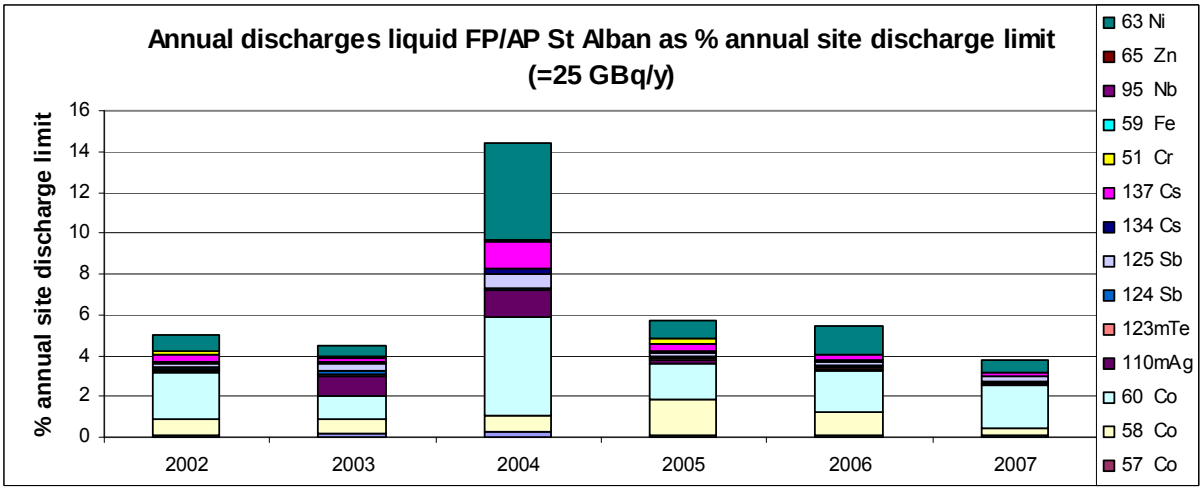
Appendix A-19: Annual discharges other radionuclides liquid Paluel, total activity (GBq) and as percentage of annual site discharge limit.



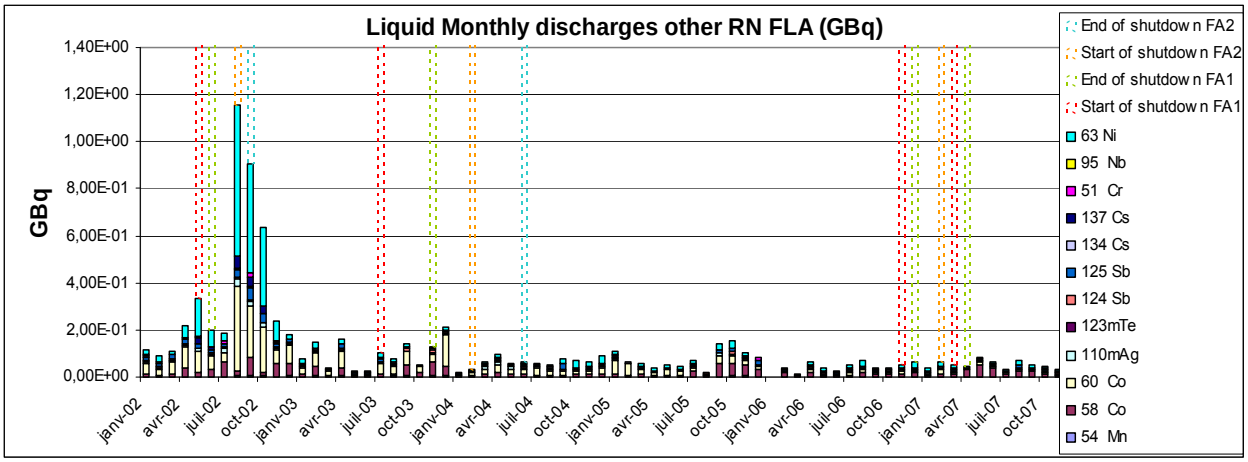


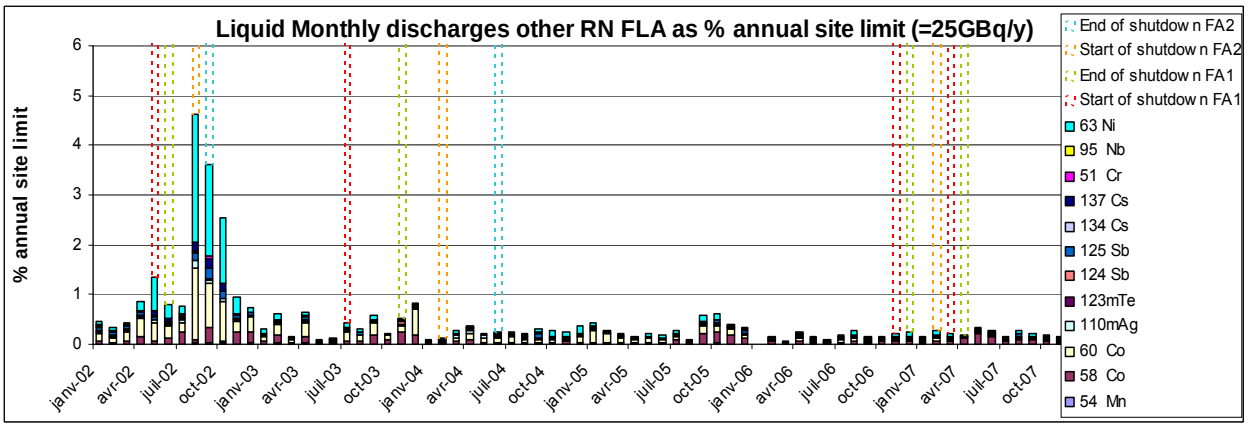
Appendix A-20: Annual discharges other radionuclides liquid St Alban, total activity (GBq) and as percentage of annual site discharge limit.

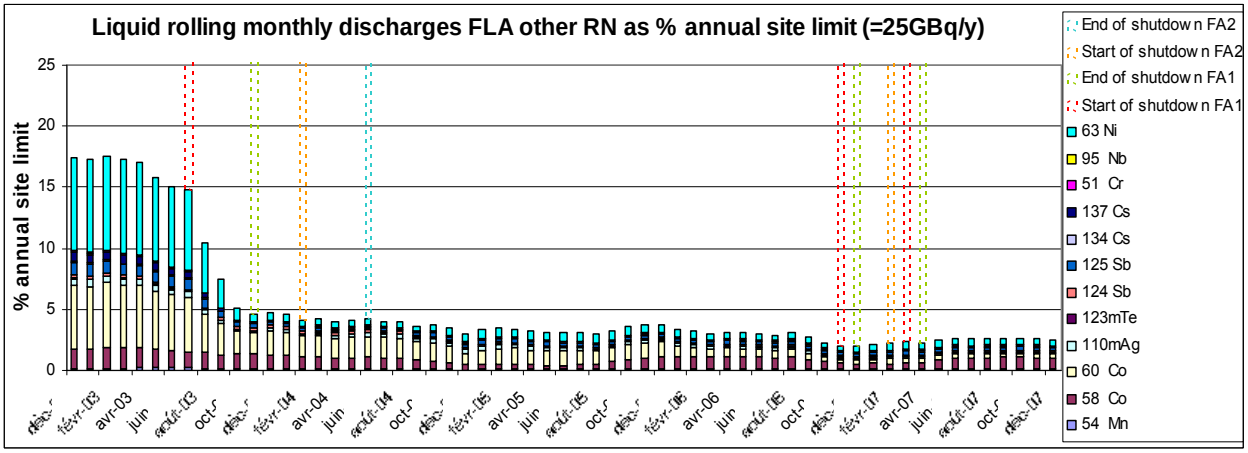




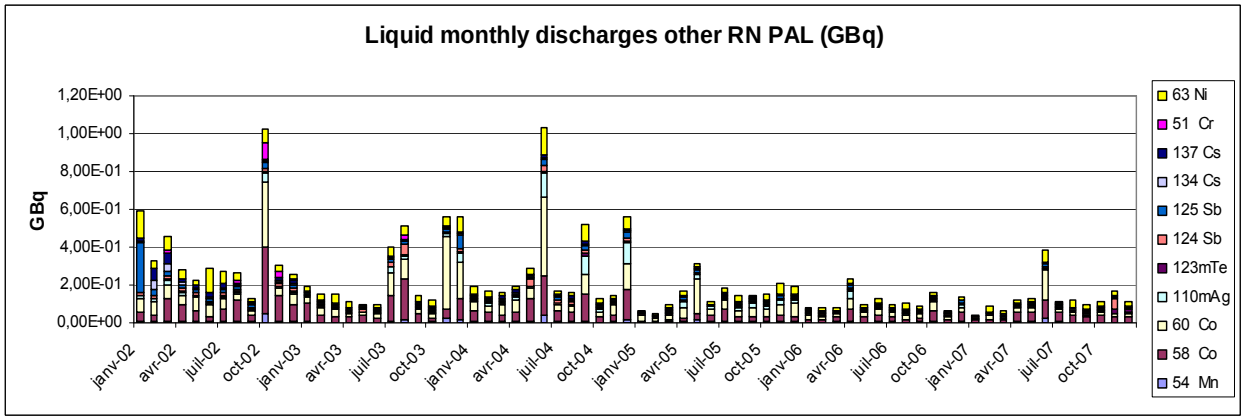
Appendix A-21: Monthly and rolling monthly discharges other radionuclides liquid Flamanville, total activity (GBq) and as percentage of annual site discharge limit.

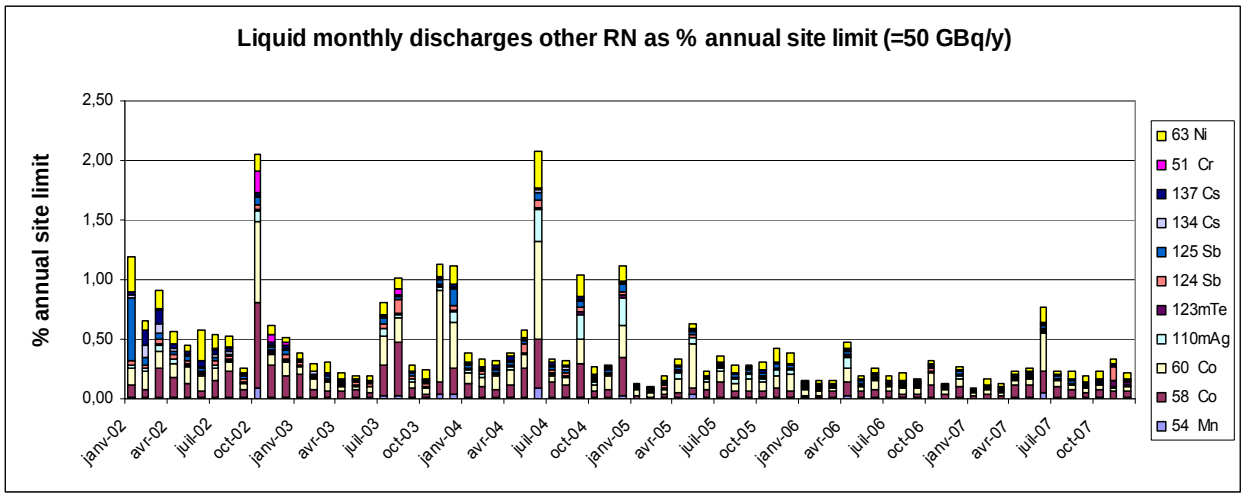


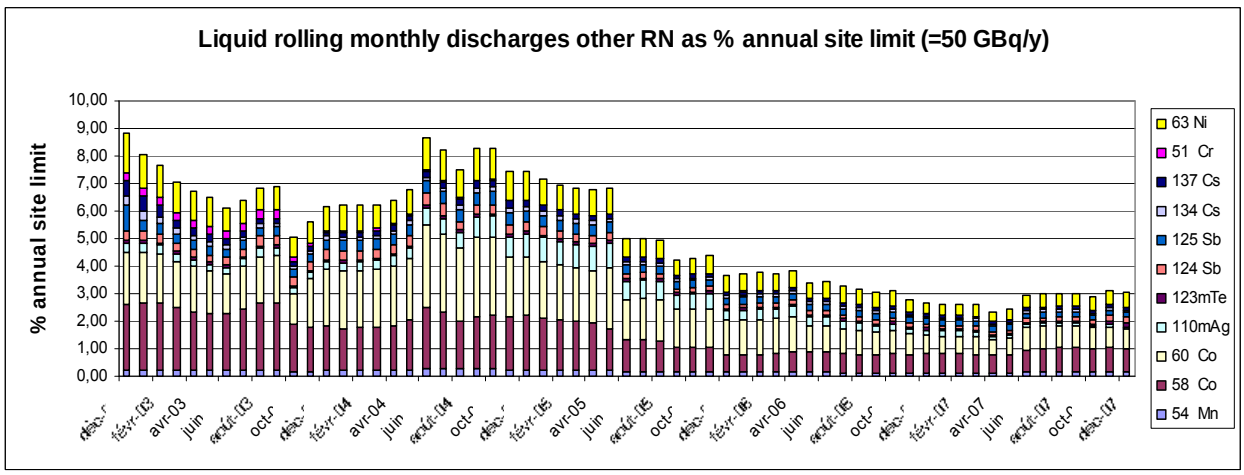




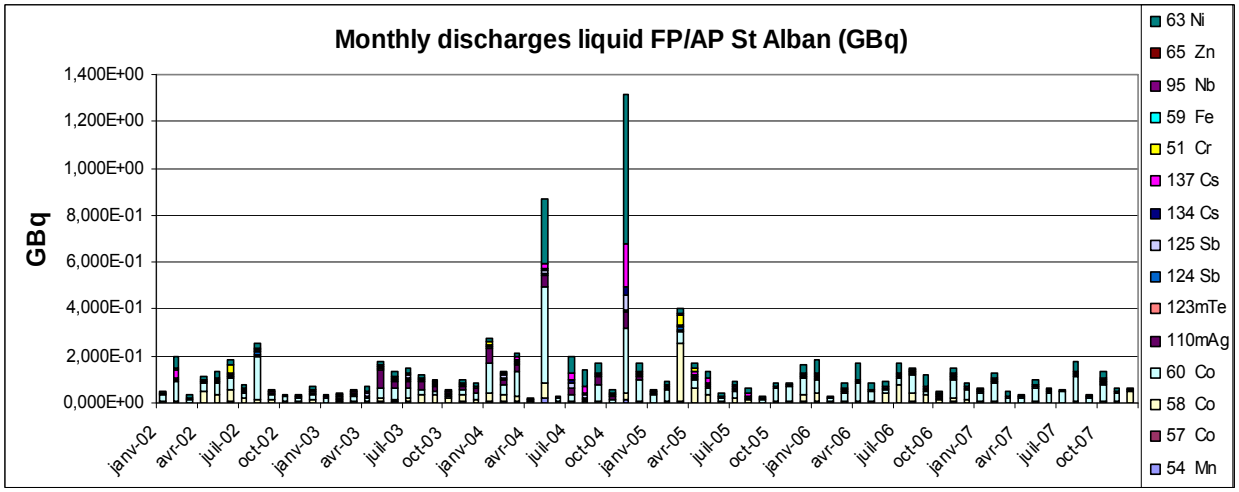
Appendix A-22: Monthly and rolling monthly discharges other radionuclides liquid Paluel, total activity (GBq) and as percentage of annual site discharge limit.

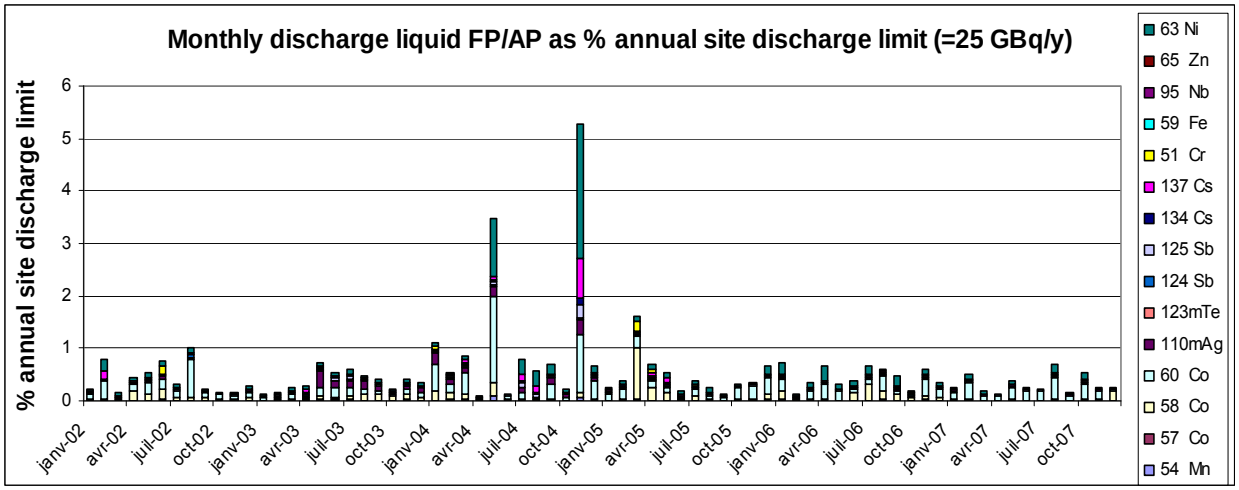


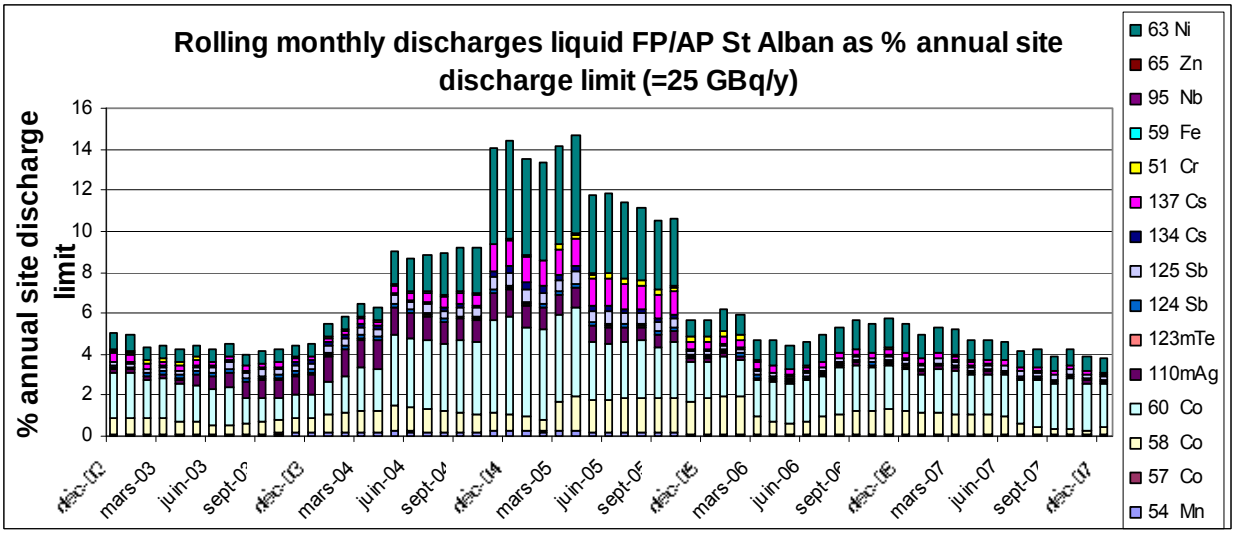




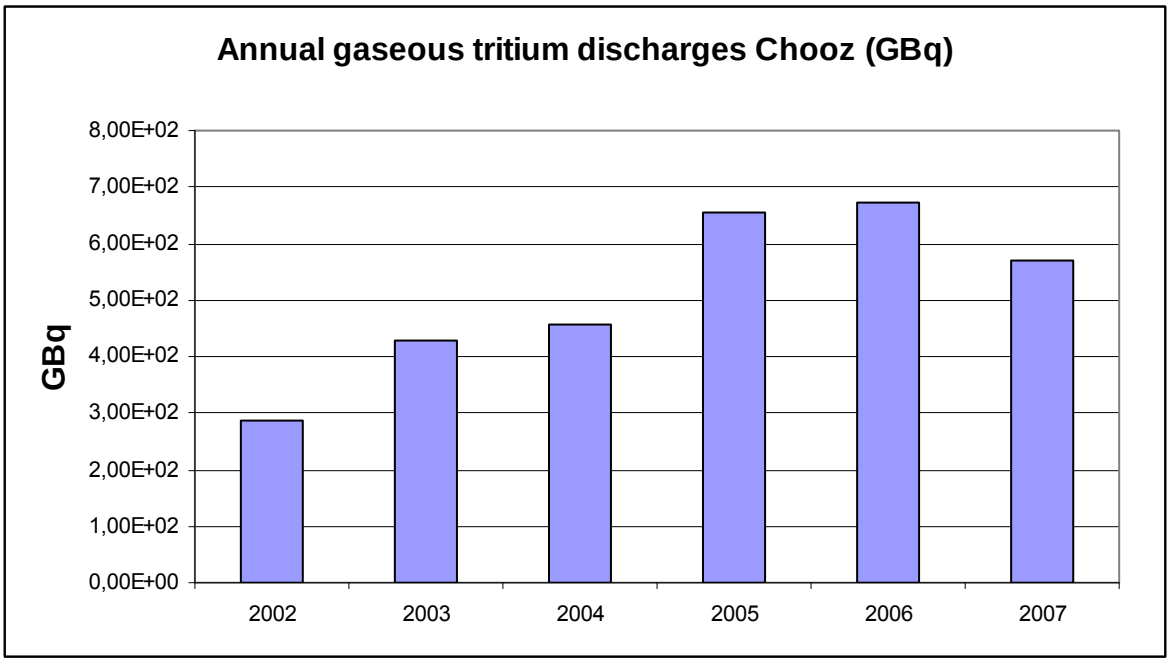
Appendix A-23: Monthly and rolling monthly discharges other radionuclides liquid St Alban, total activity (GBq) and as percentage of annual site discharge limit.

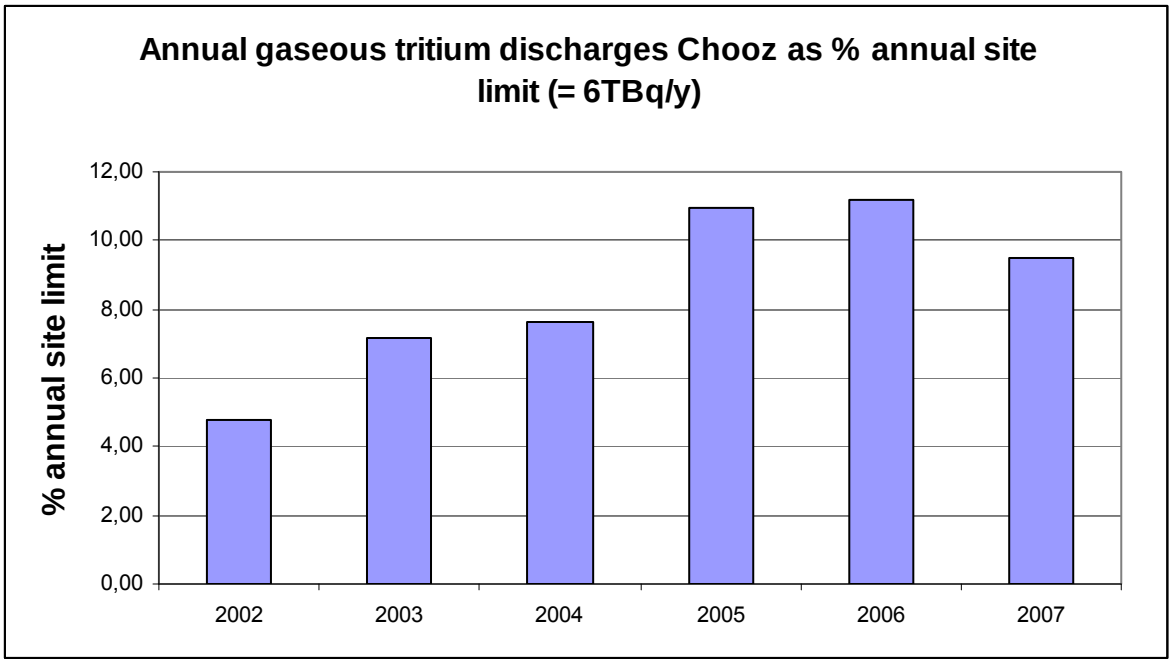




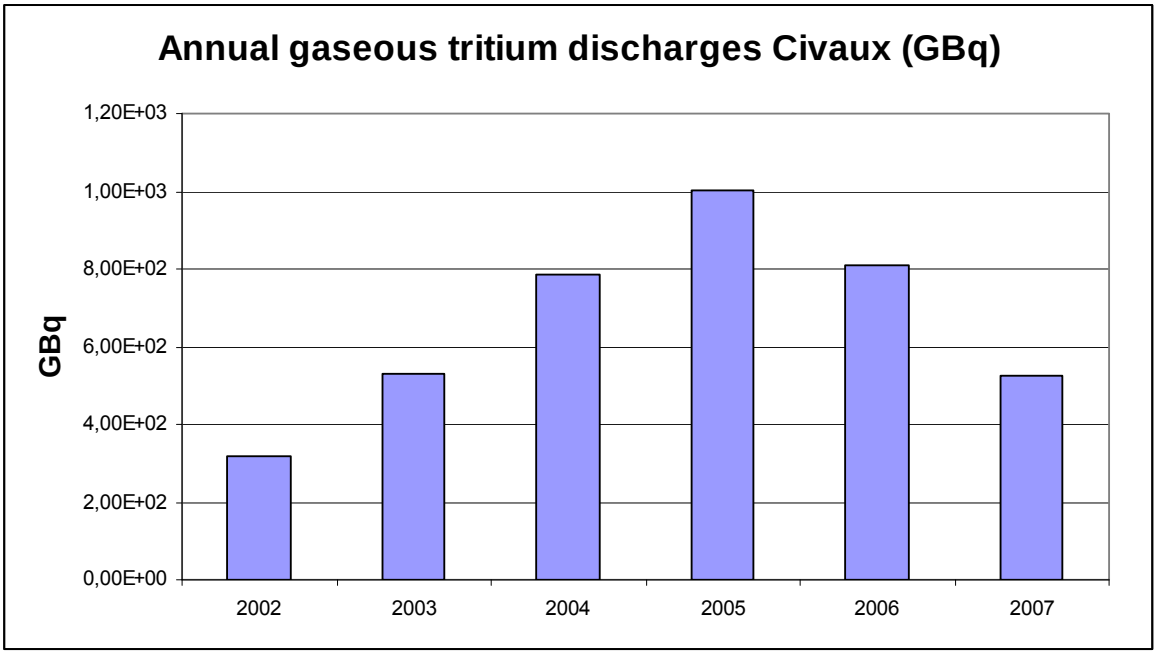


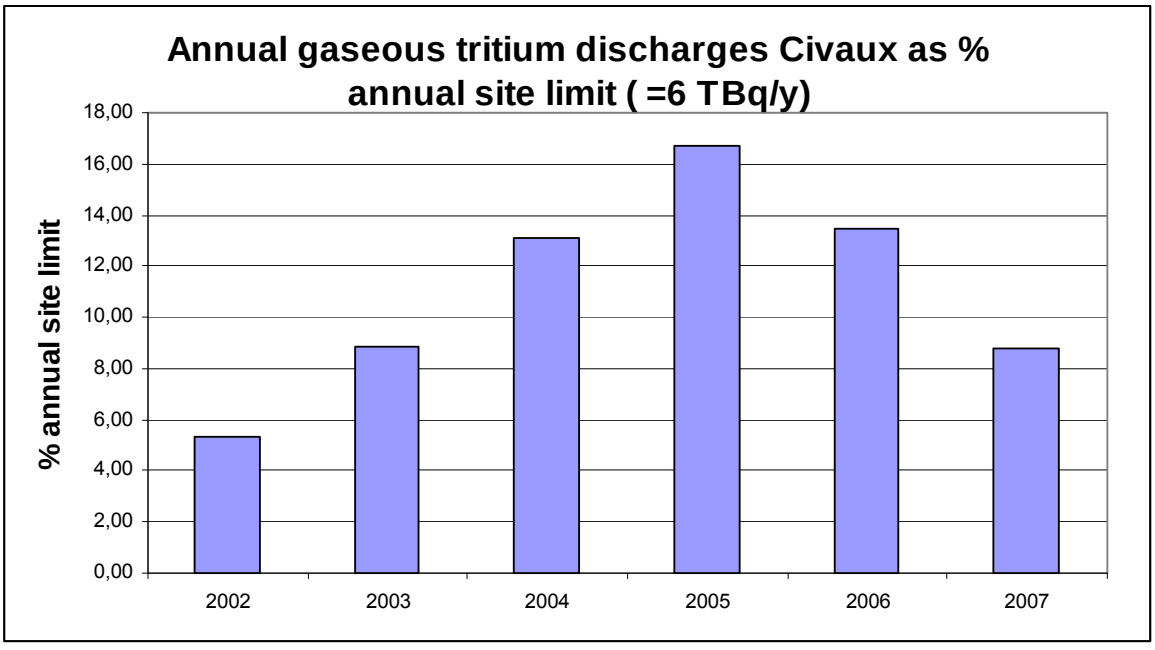
Appendix A-24: Annual discharges gaseous tritium (H-3) Chooz, total activity (GBq) and as percentage of annual site discharge limit.



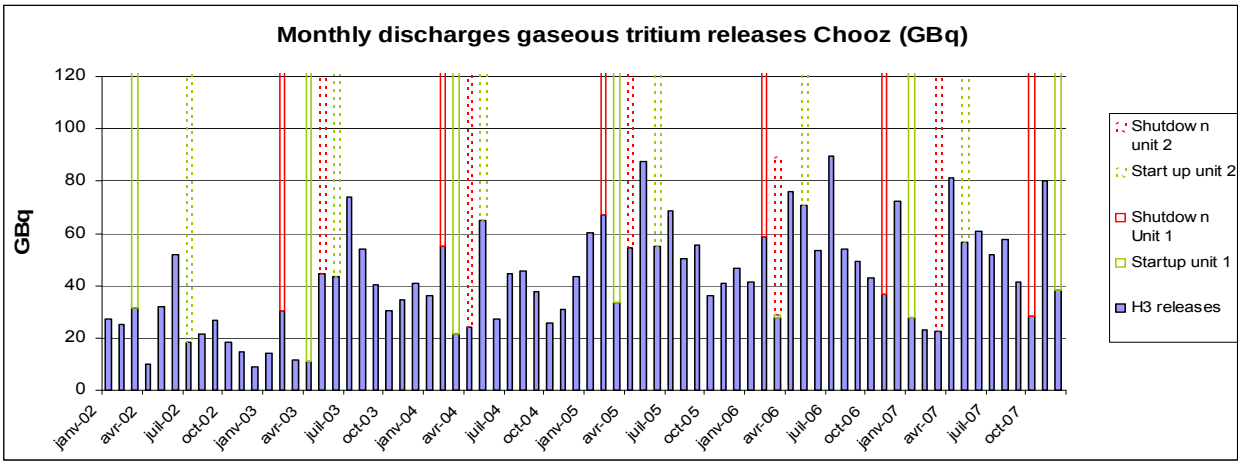


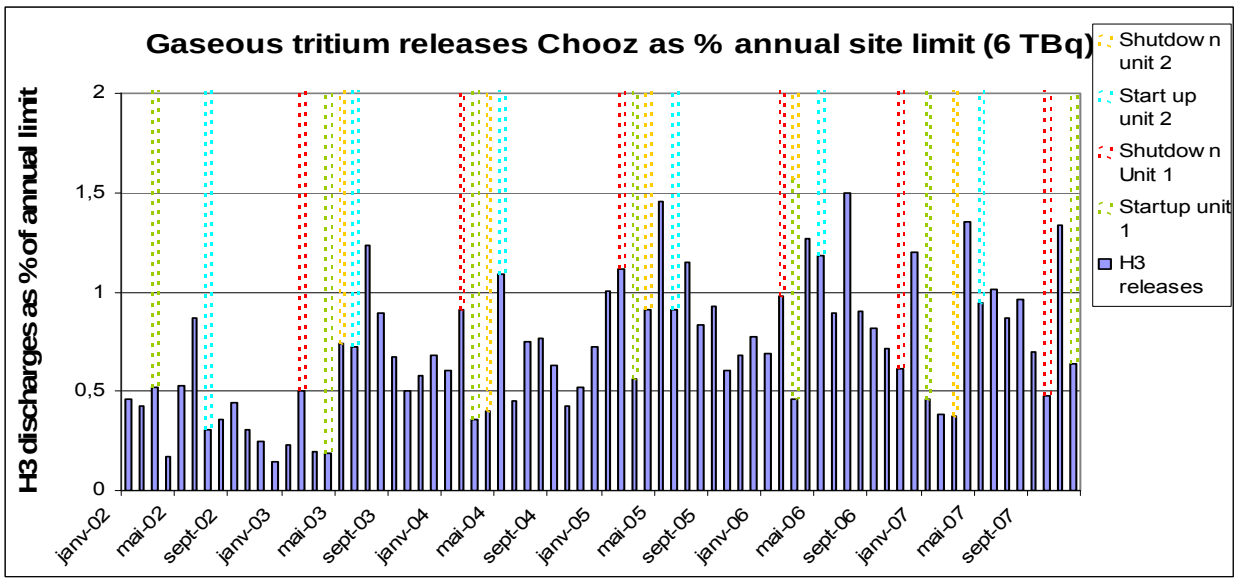
Appendix A-25: Annual discharges gaseous tritium (H-3) Civaux, total activity (GBq) and as percentage of annual site discharge limit.

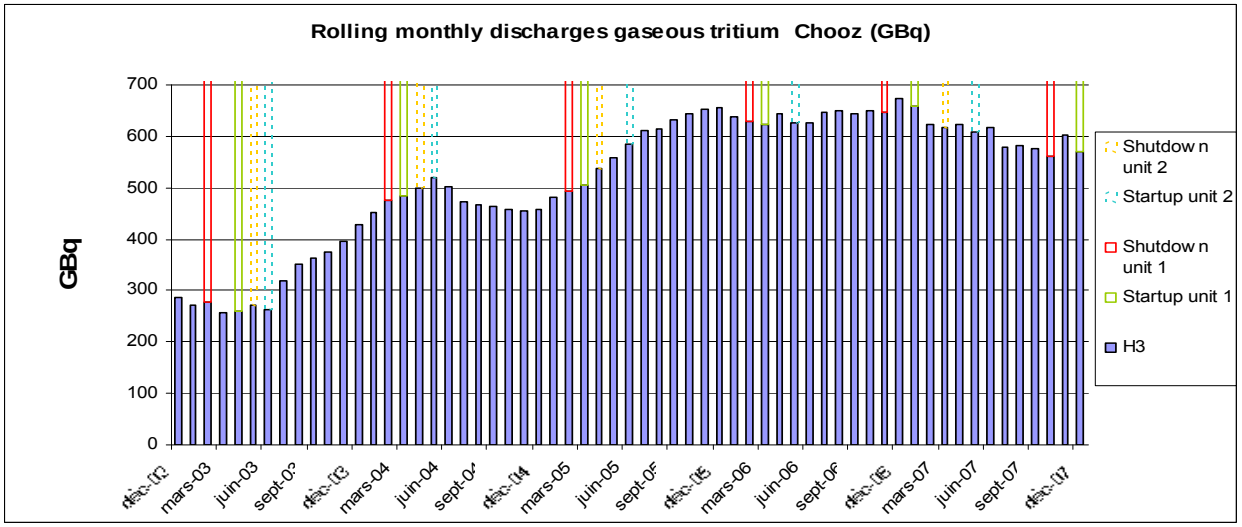




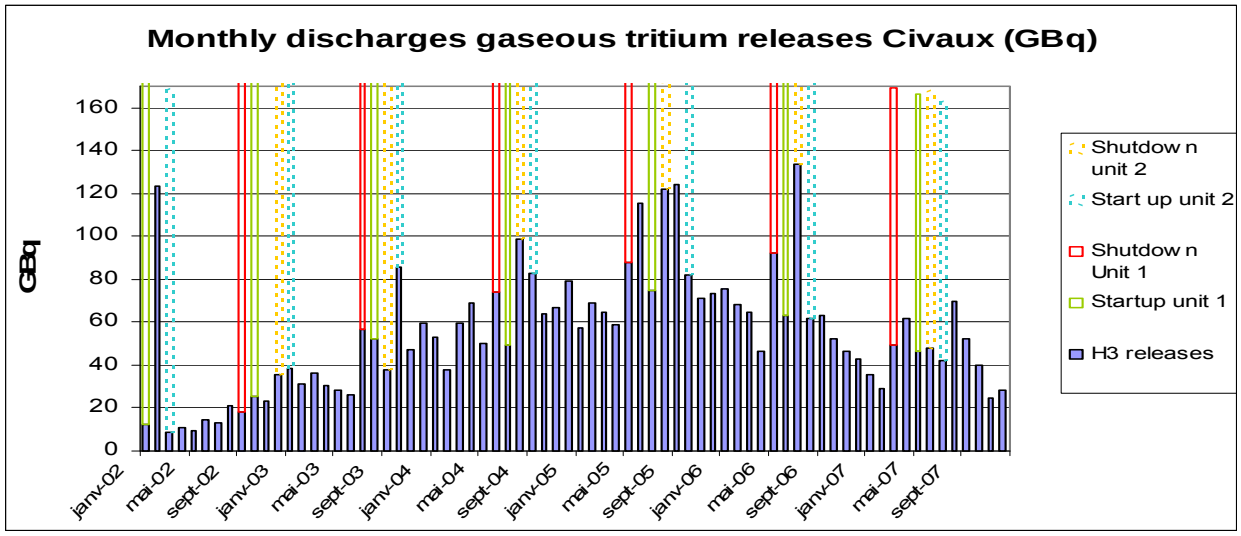
Appendix A-26: Monthly and rolling monthly discharges gaseous tritium (H-3) Chooz, total activity (GBq) and as percentage of site annual discharge limit.

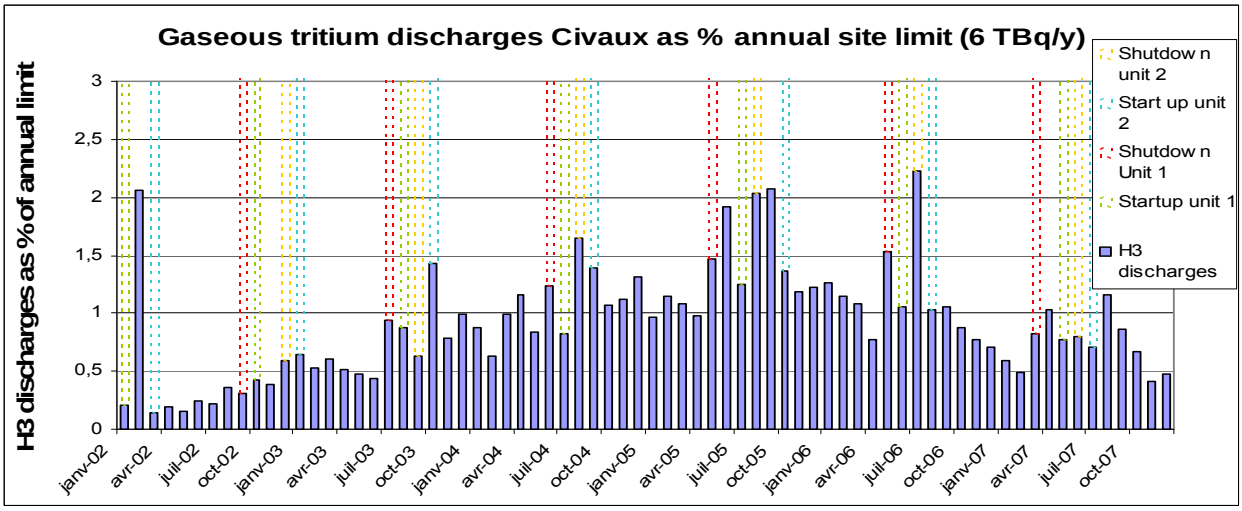


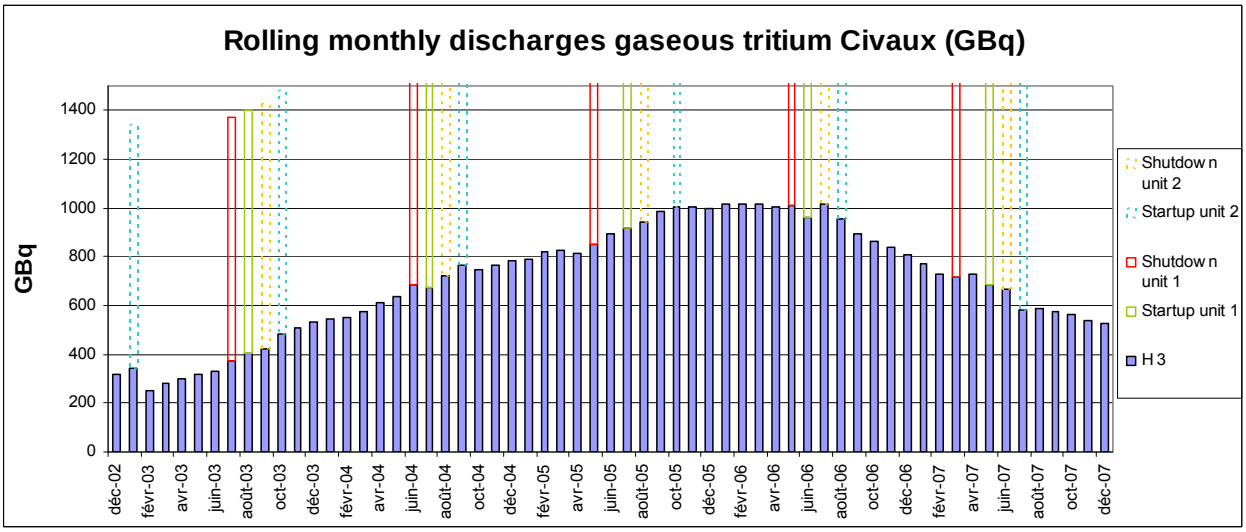




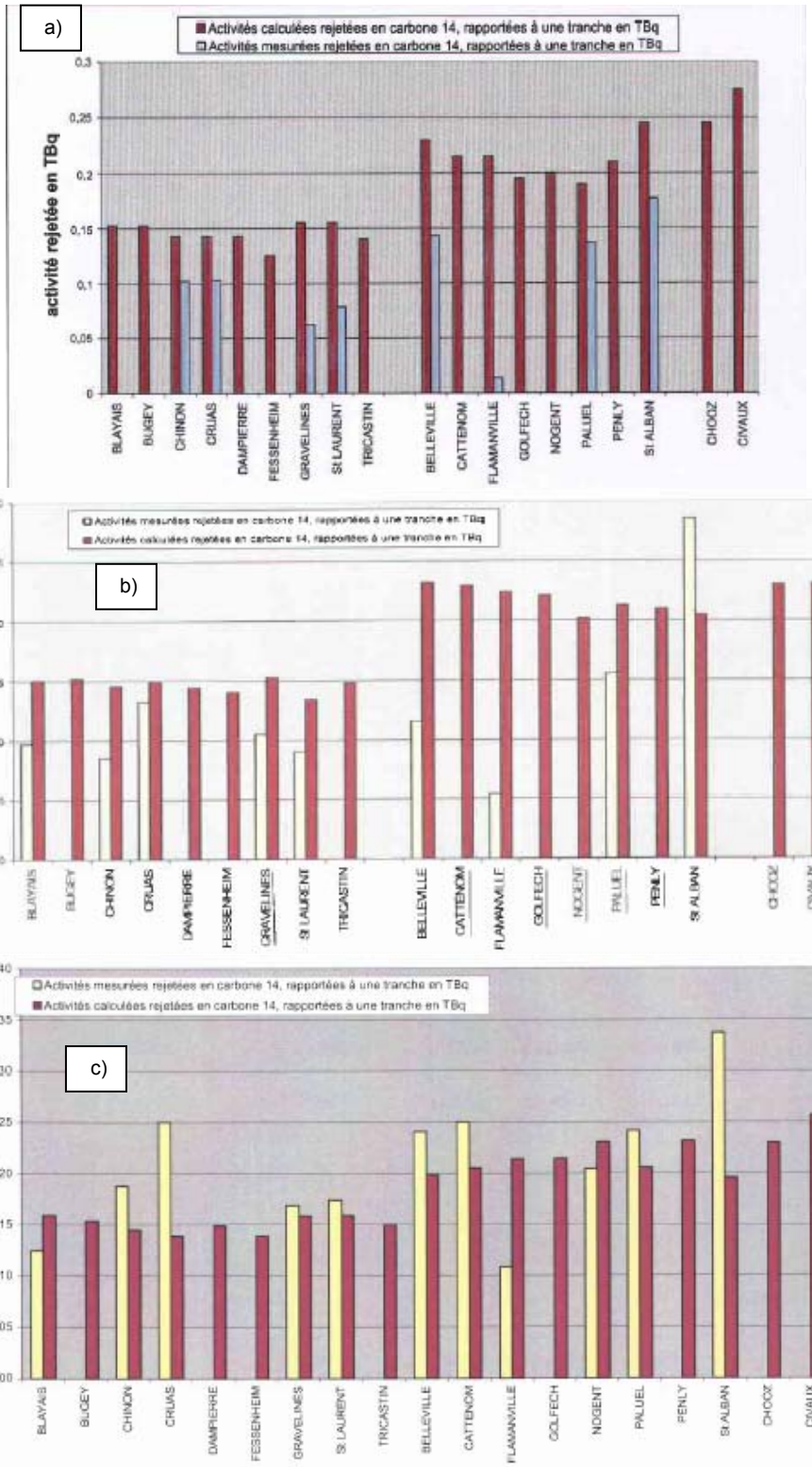
Appendix A-27: Monthly and rolling monthly discharges gaseous tritium (H-3) Civaux, total activity (GBq) and as percentage of annual site discharge limit.



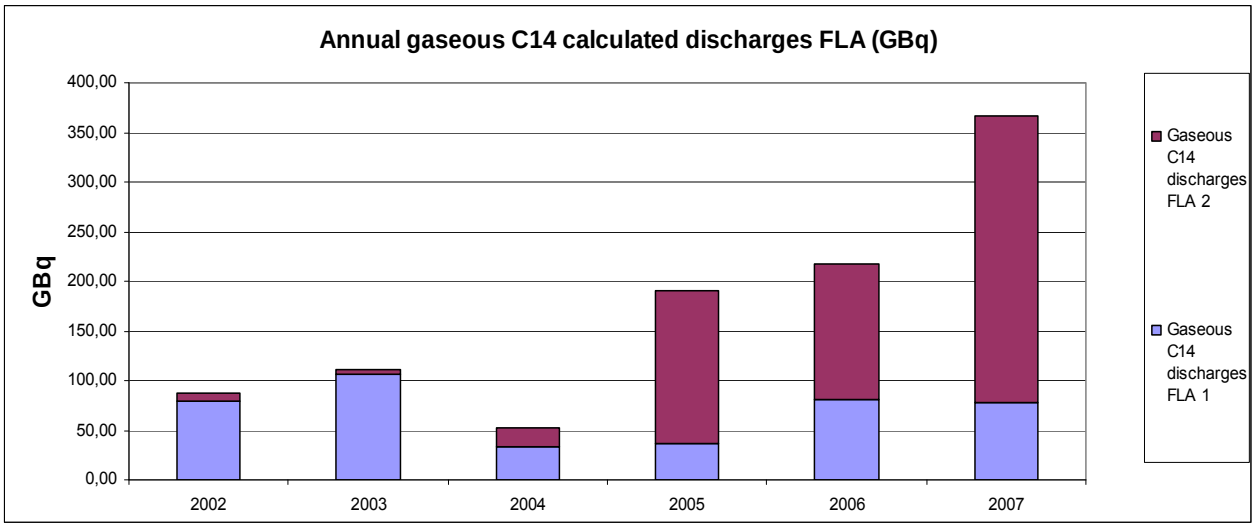


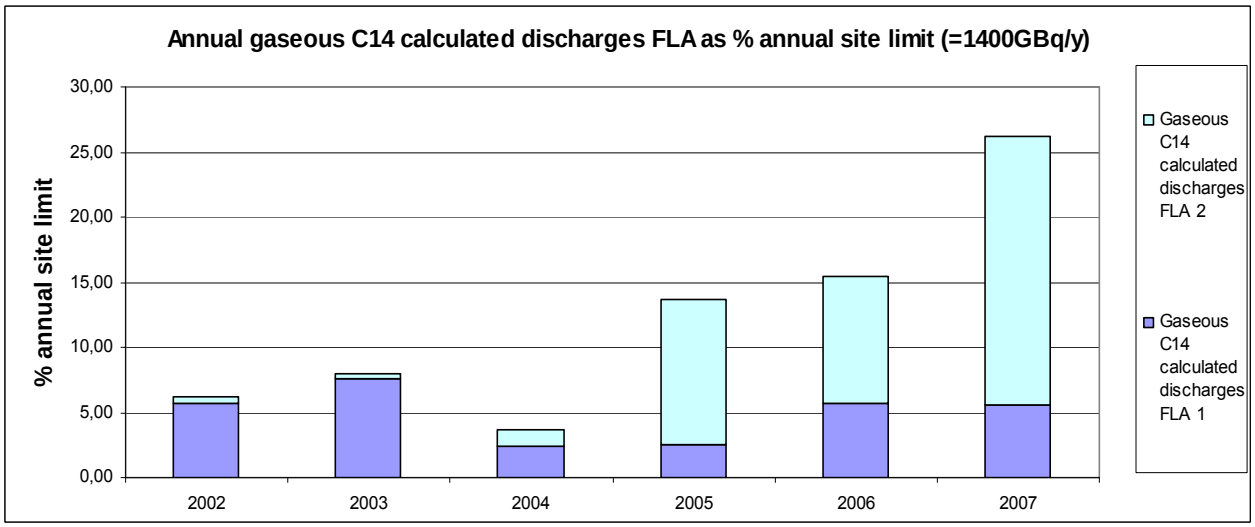


Appendix A-28: Gaseous C-14 Annual Activity (discharged and calculated) in TBq per 1300 MW(e) unit for a) 2004, b) 2005 and c) 2006

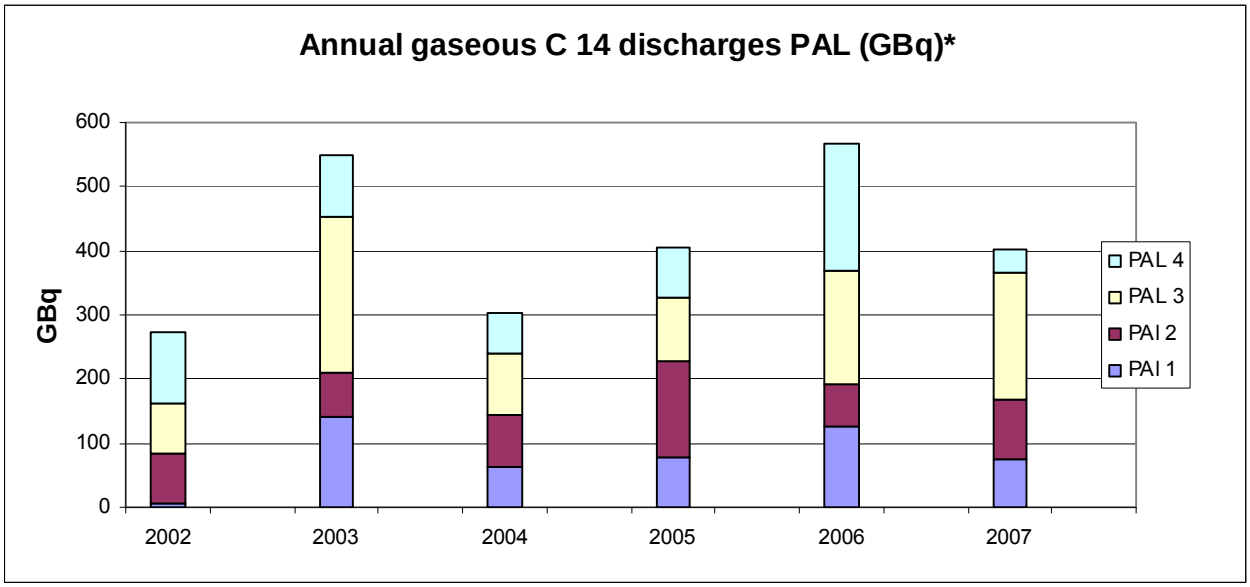


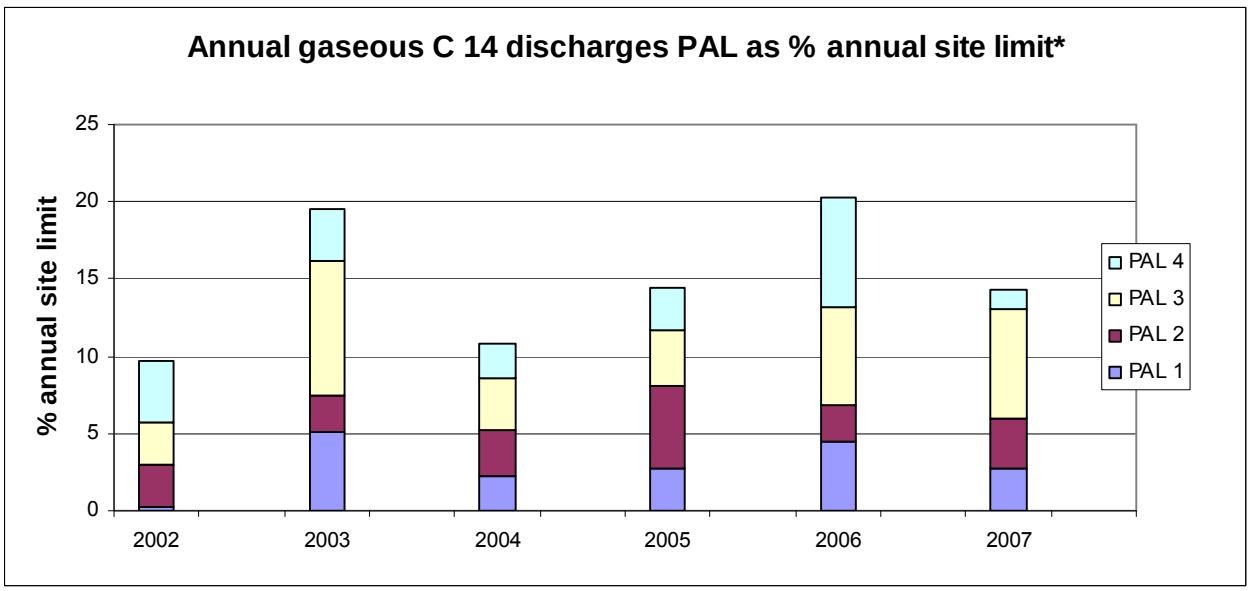
Appendix A-29: Annual discharges gaseous C-14 Flamanville, total activity (GBq) and as percentage of annual site discharge limit.





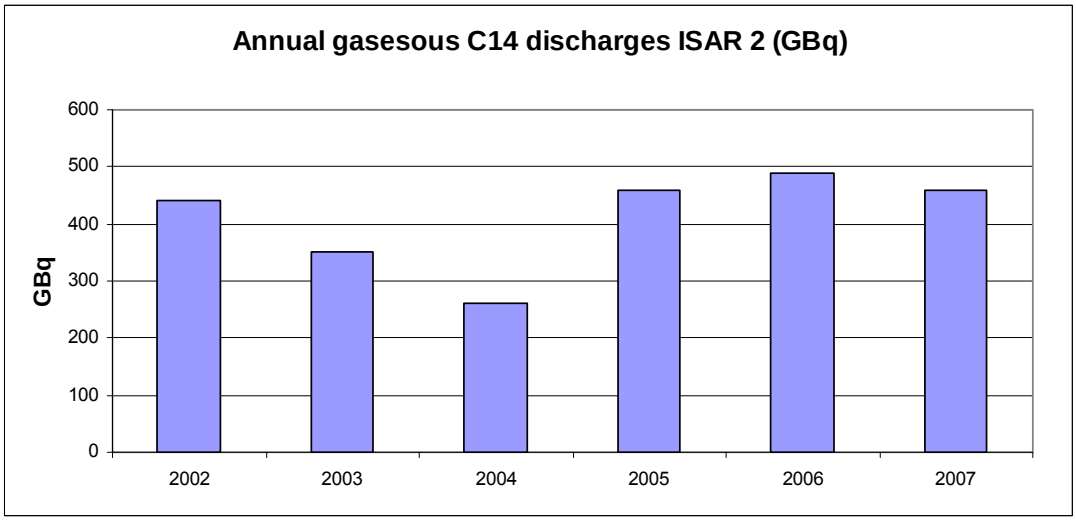
Appendix A-30: Annual discharges gaseous C-14 Paluel, total activity (GBq) and as percentage of annual site discharge limit.

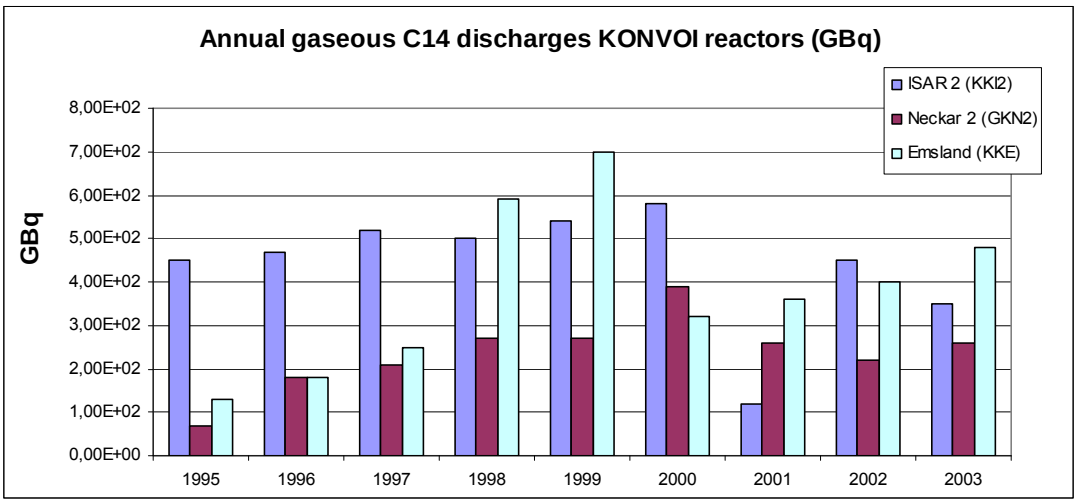




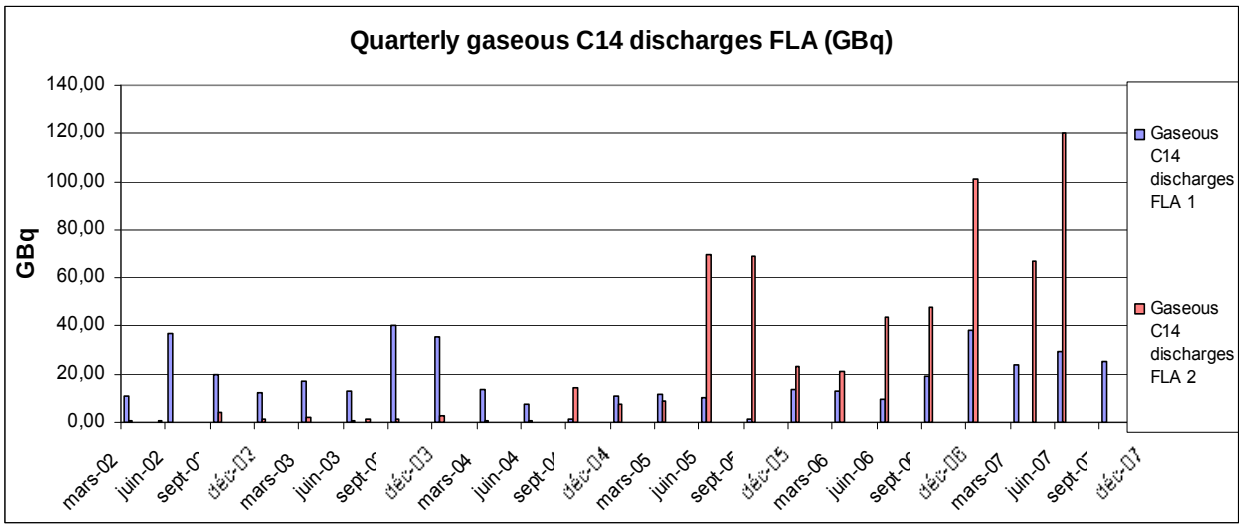
*: the annual data obtained for Paluel are to be considered carefully as some of the records were not available, and therefore only the first two quarters of each year are displayed on the graphs. The annual discharge data presented here are therefore expected to be largely underestimated as only half of the year's discharges were considered

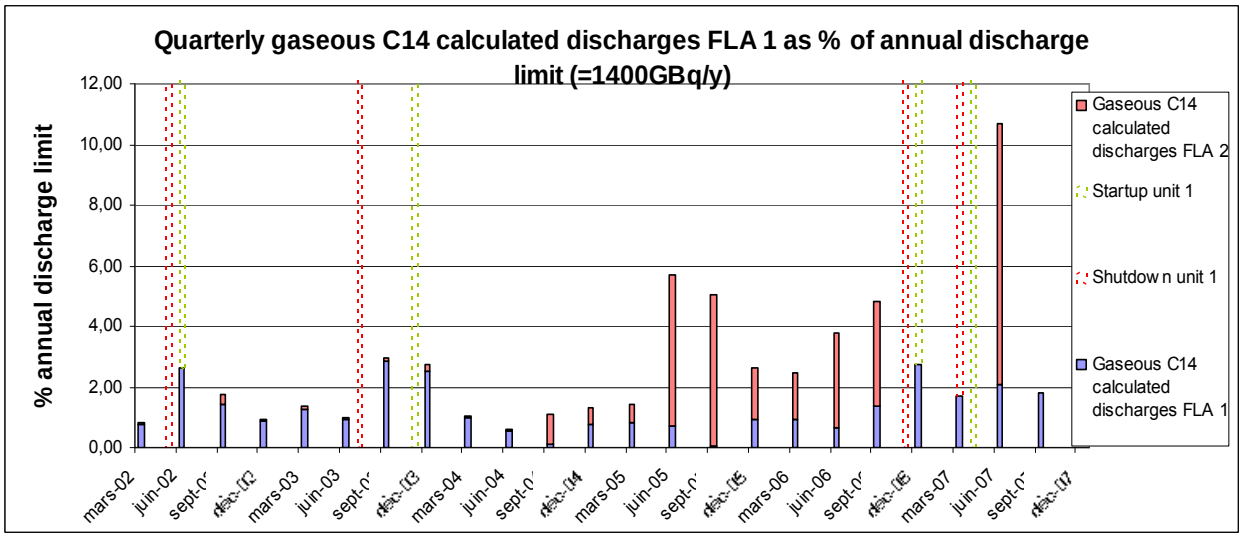
Appendix A-31: Annual activity discharged from gaseous C-14 KONVOI reactors over the period 1995-2003 and ISAR over 2002-2007, total activity (GBq).



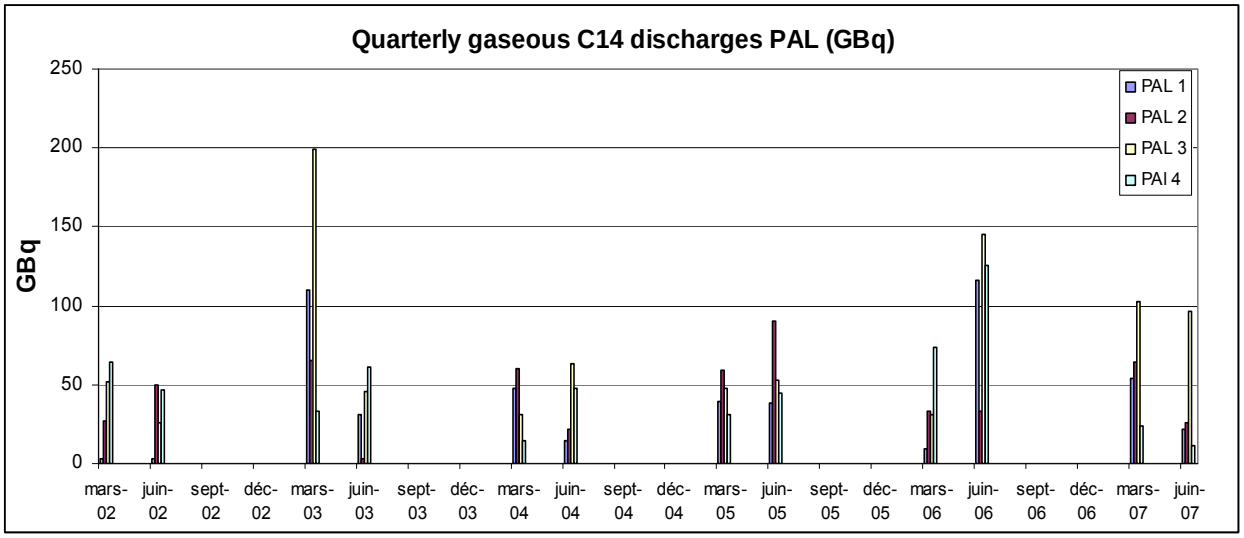


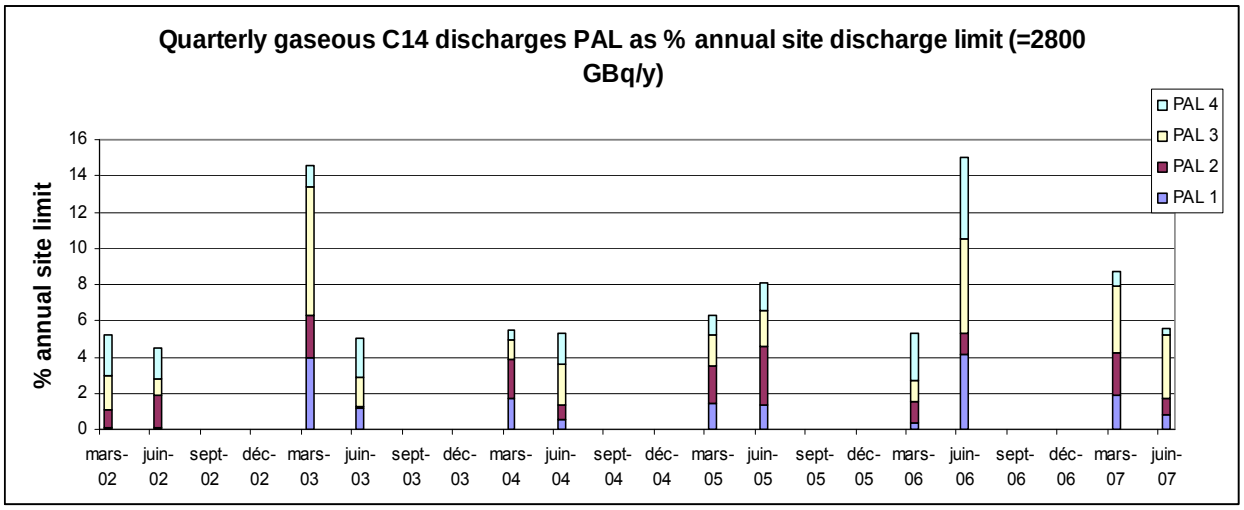
Appendix A-32: Quarterly discharges gaseous C-14 Flamanville, total activity (GBq) and as percentage of annual site discharge limit.





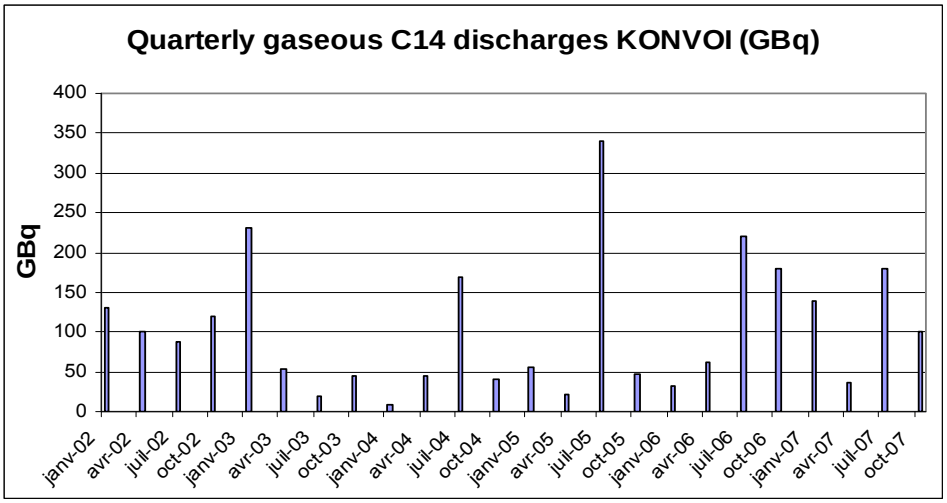
Appendix A-33: Quarterly discharges gaseous C-14 Paluel, total activity (GBq) and as percentage of annual site discharge limit.

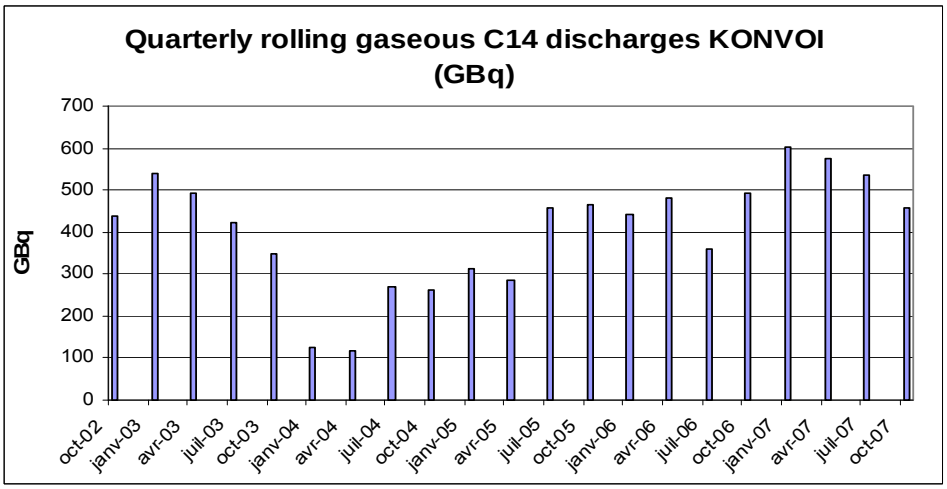




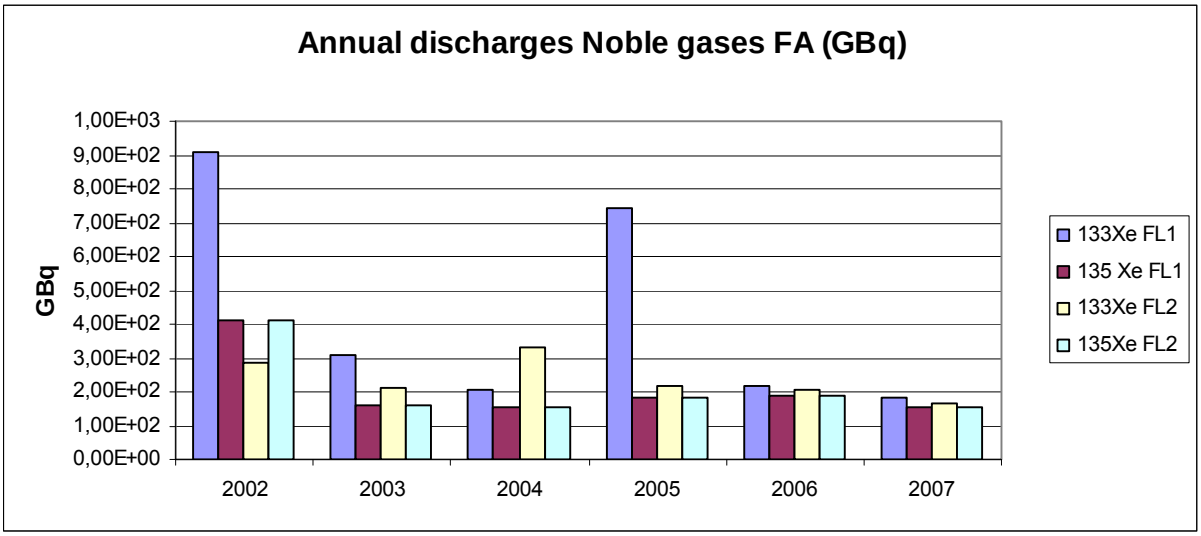
Note: The data obtained for Paluel are to be considered carefully as some of the records were not available, and therefore only the first two quarters of each year are displayed on the graphs.

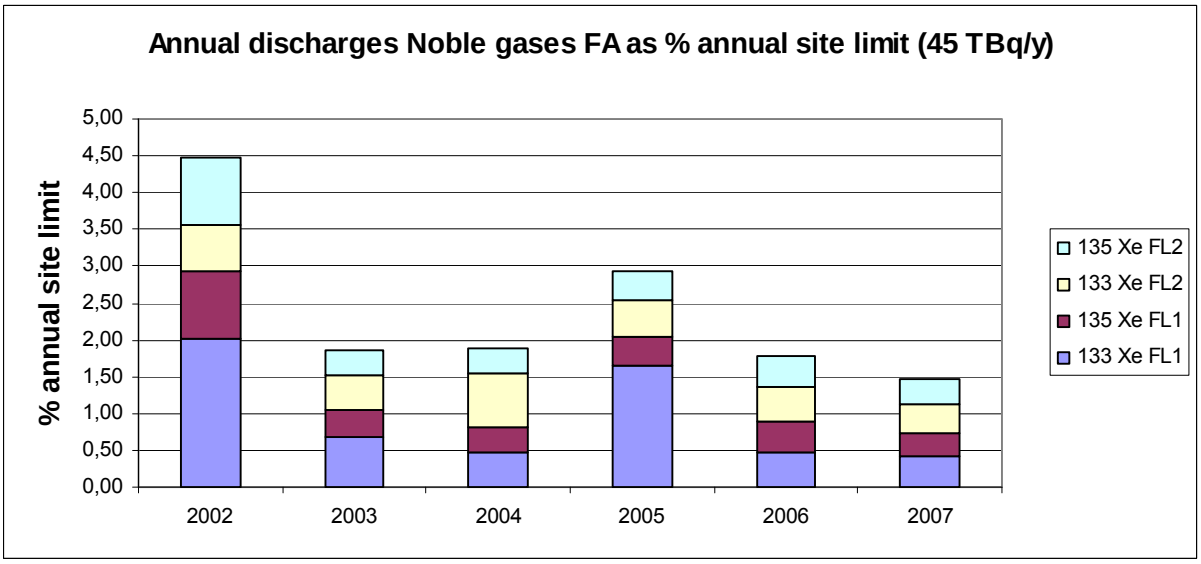
Appendix A-34: Quarterly discharges gaseous C-14 ISAR 2 KONVOI, total activity (GBq).



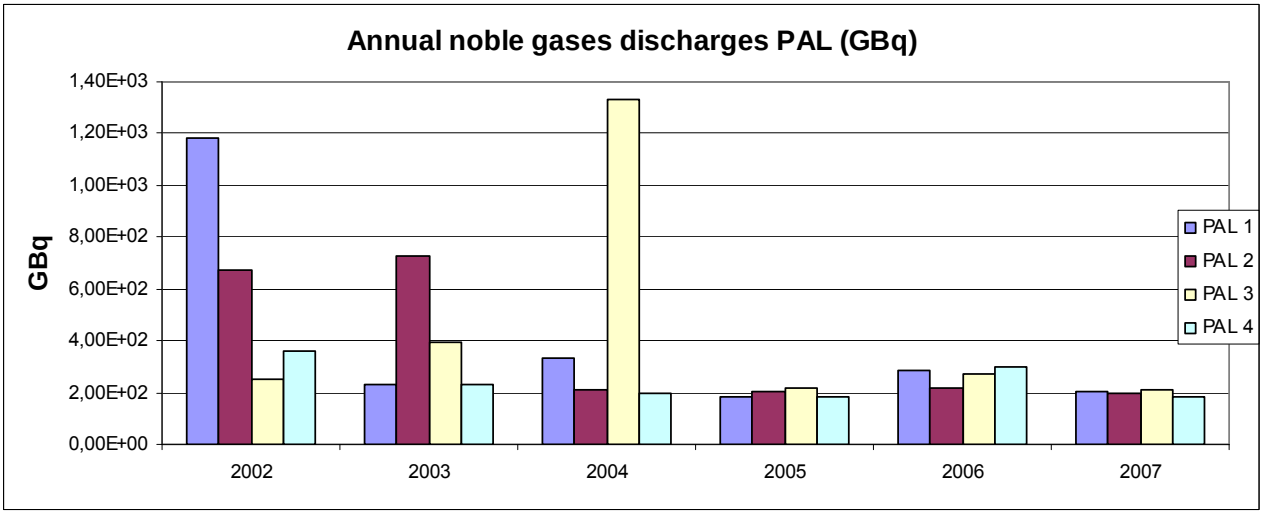


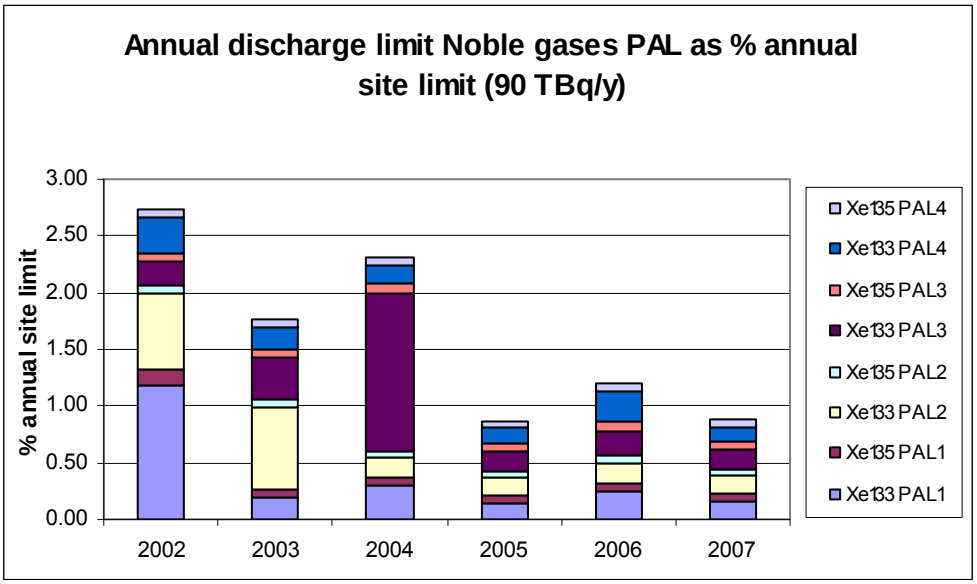
Appendix A-35: Annual discharges noble gases Flamanville, total activity (GBq) and as percentage of annual site discharge limit.



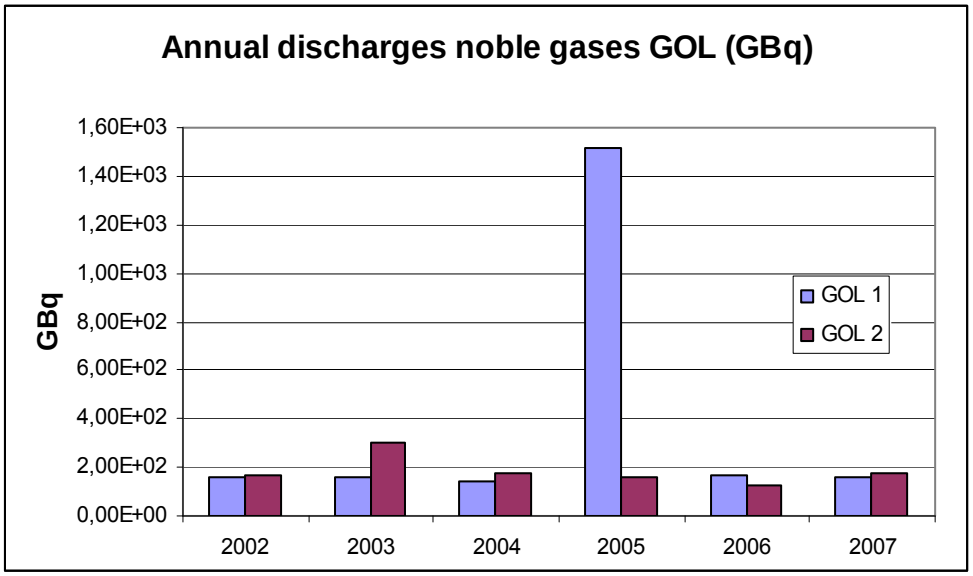


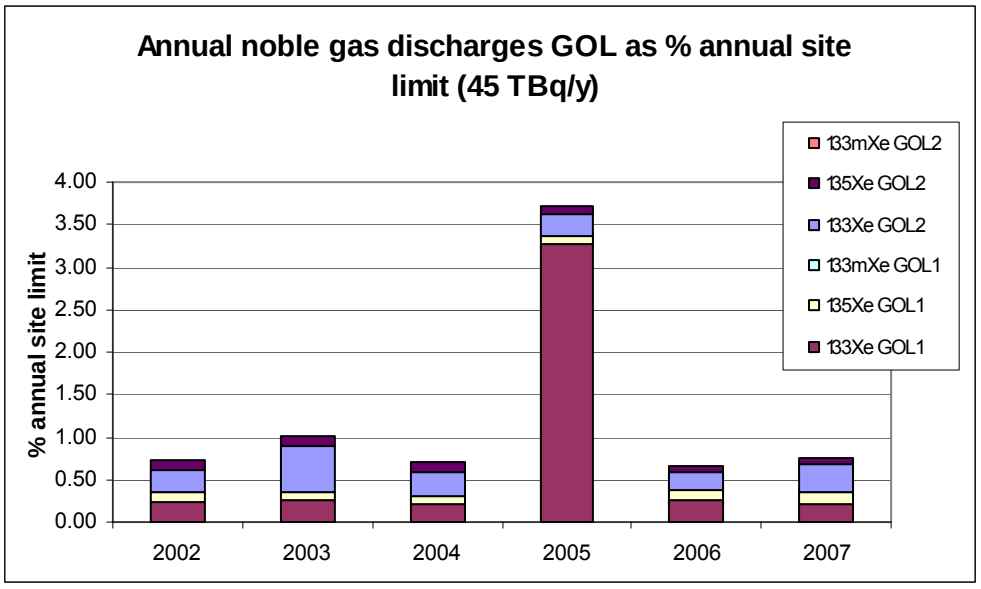
Appendix A-36: Annual discharges noble gases Paluel, total activity (GBq) and as percentage of annual site discharge limit.



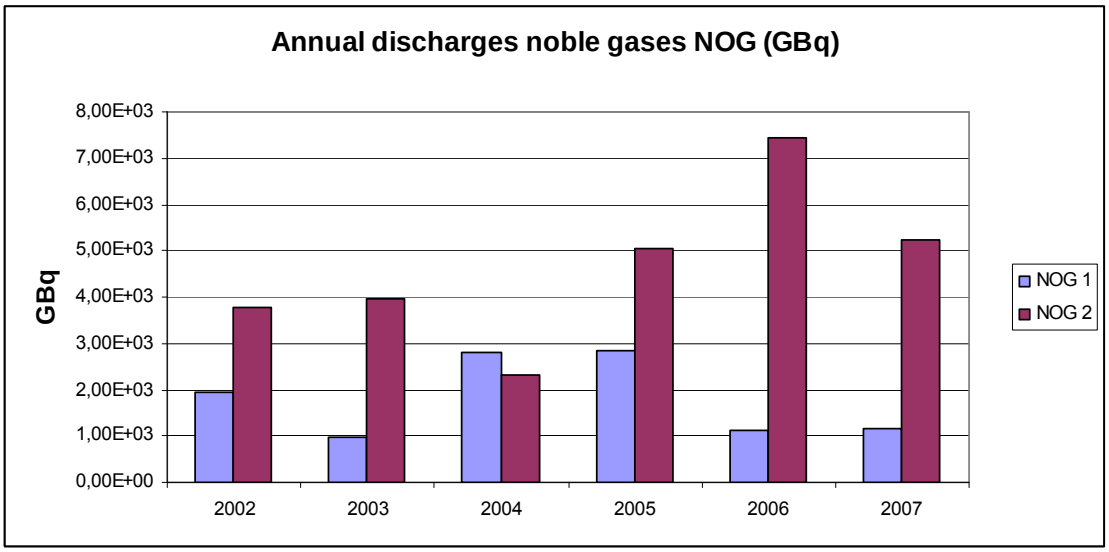


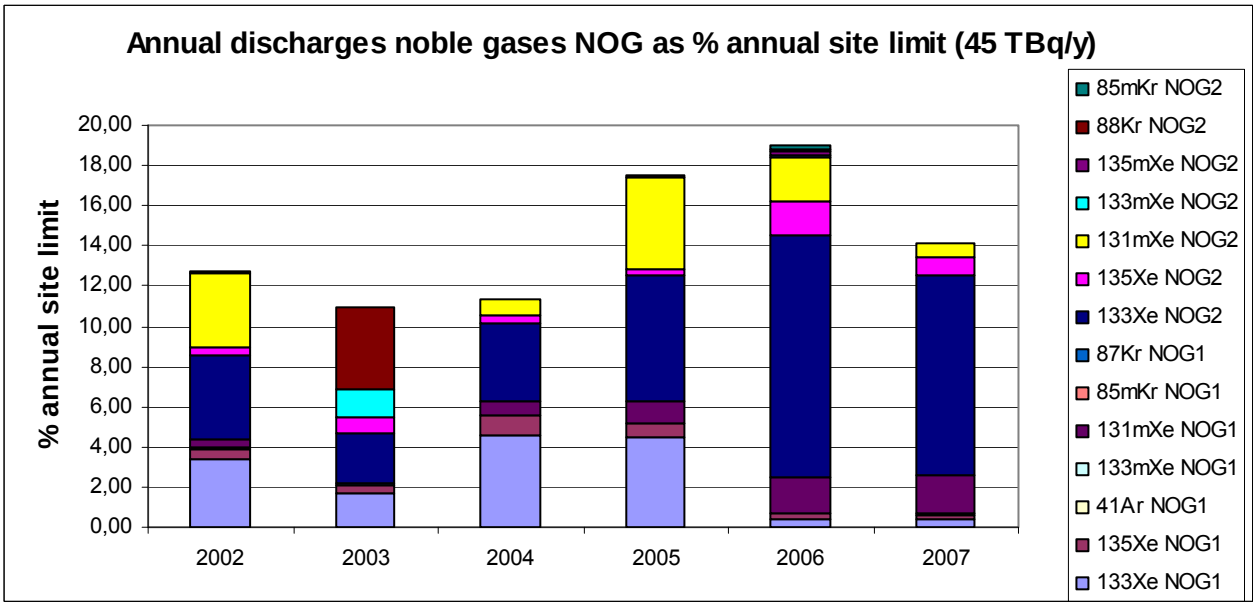
Appendix A-37: Annual discharges noble gases Golfech, total activity (GBq) and as percentage of annual site discharge limit.



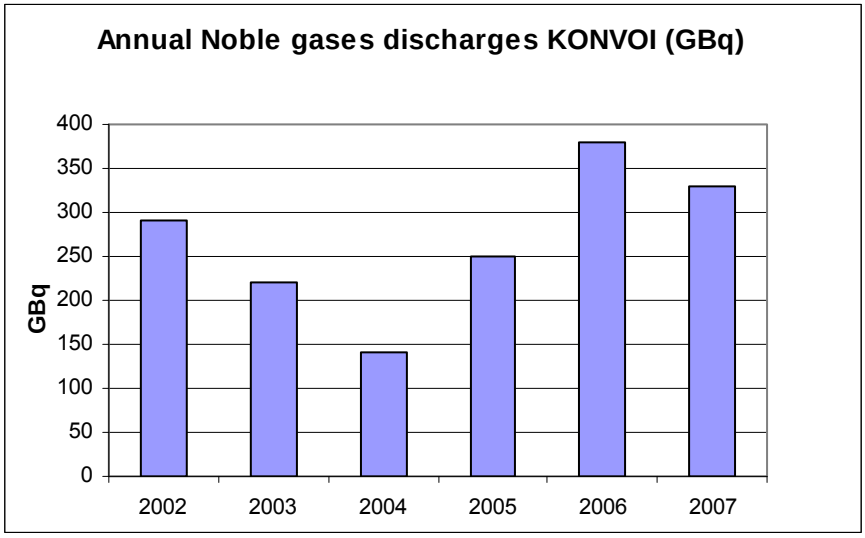


Appendix A-38: Annual discharges noble gases Nogent, total activity (GBq) and as percentage of annual site discharge limit.

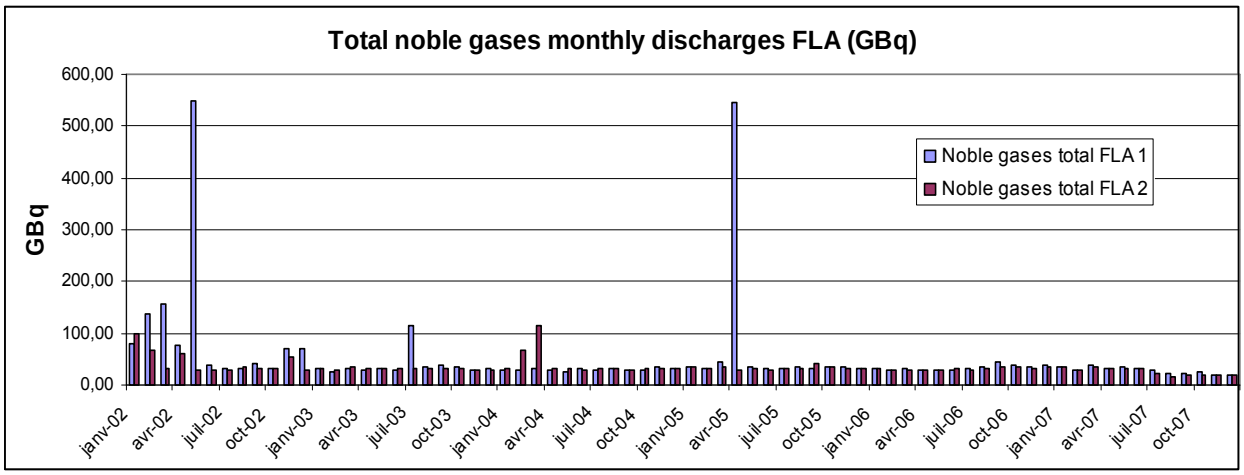


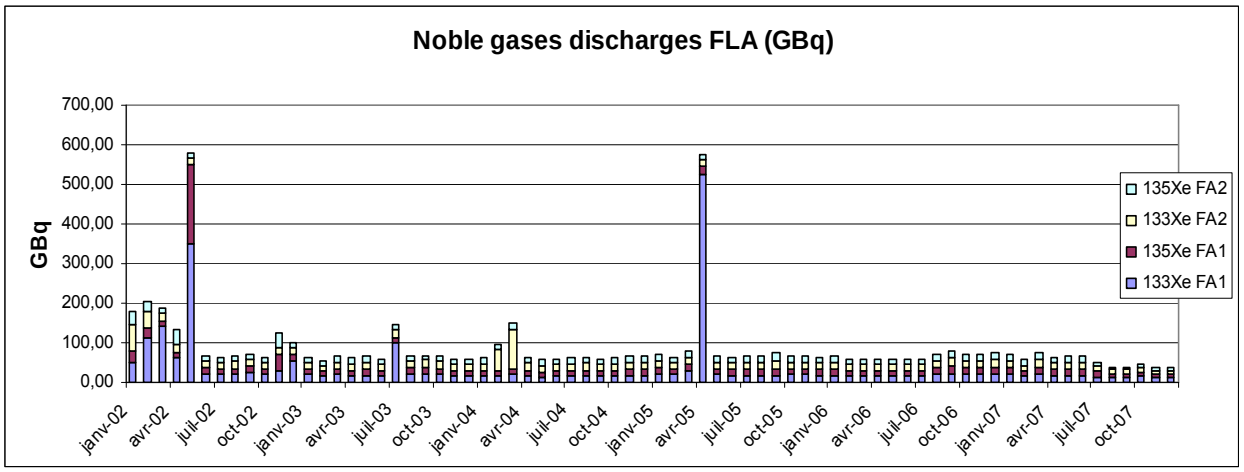


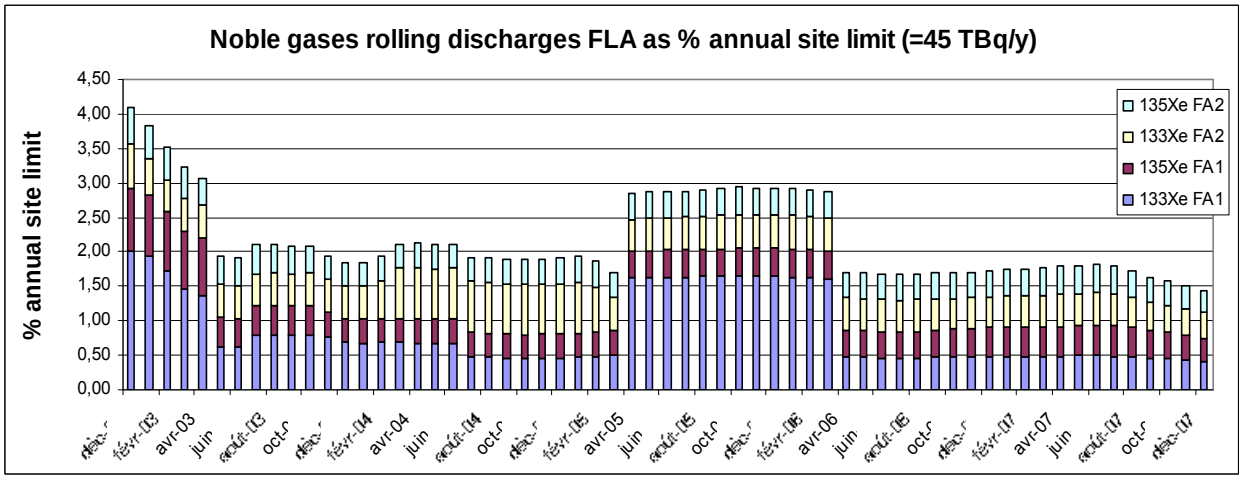
Appendix A-39: Annual discharges noble gases KONVOI ISAR 2, total activity (GBq)



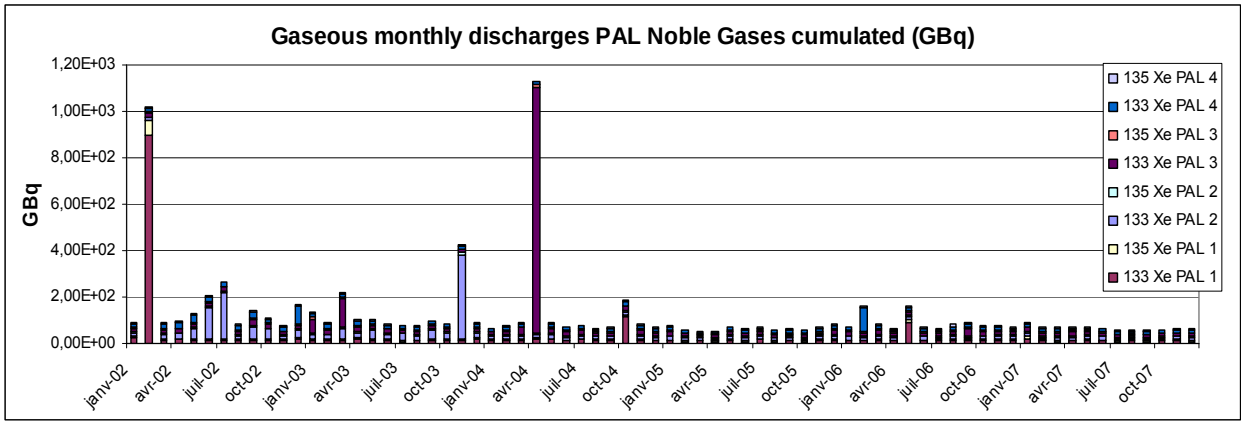
Appendix A-40: Monthly and rolling monthly discharges noble gases Flamanville, total activity (GBq) and as percentage of annual site discharge limit.

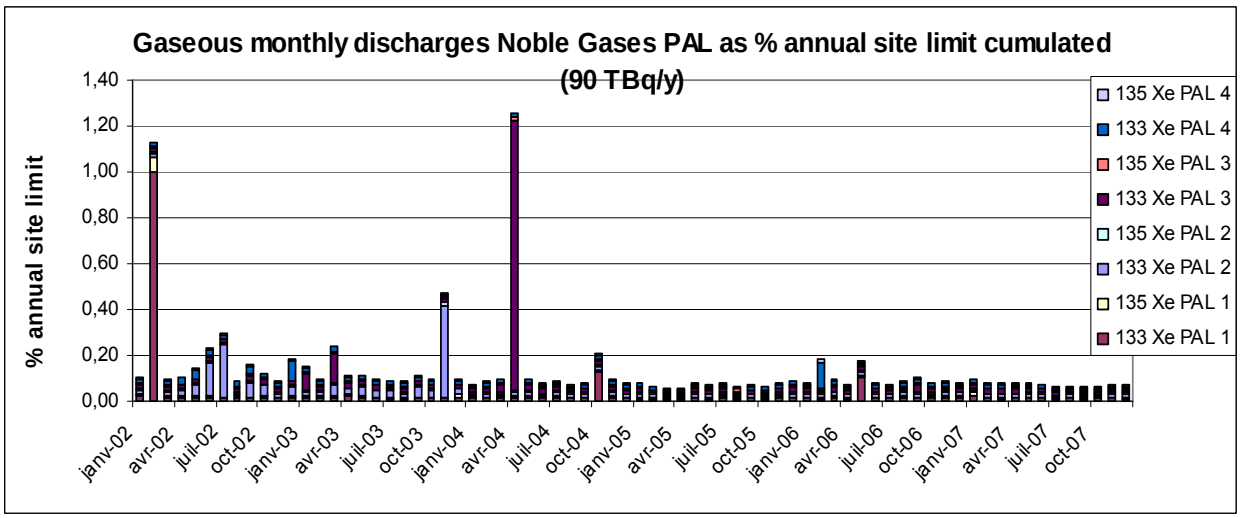


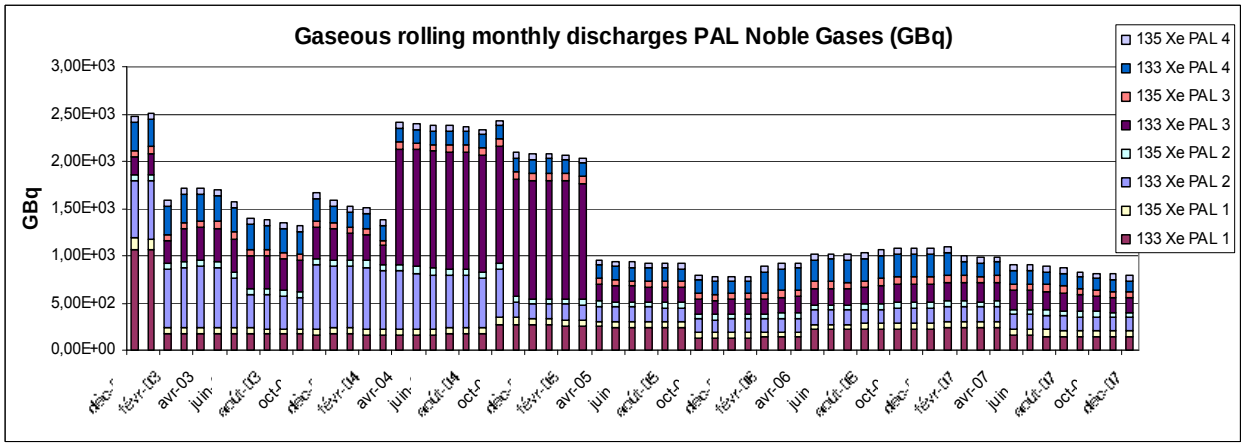




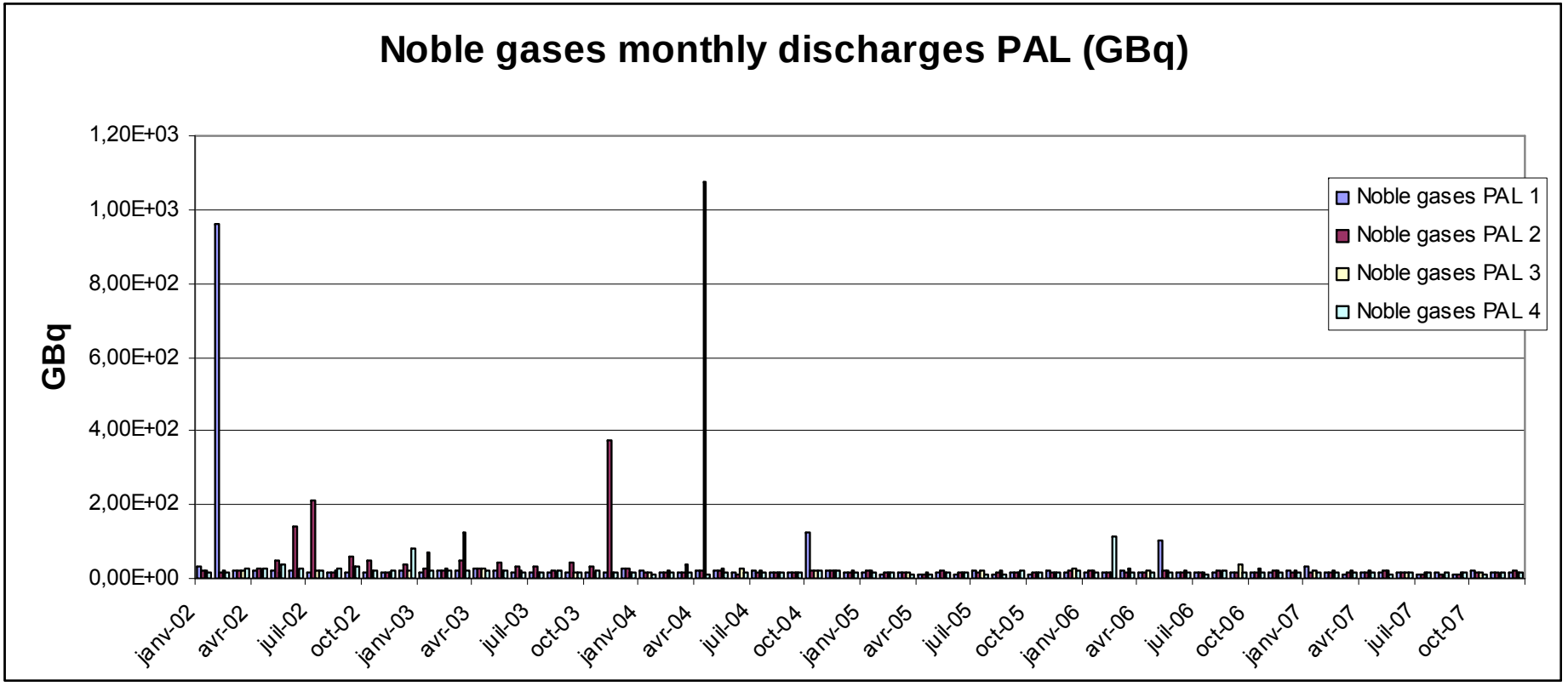
Appendix A-41: Monthly and rolling monthly discharges noble gases Paluel, total activity (GBq) and as percentage of annual site discharge limit.



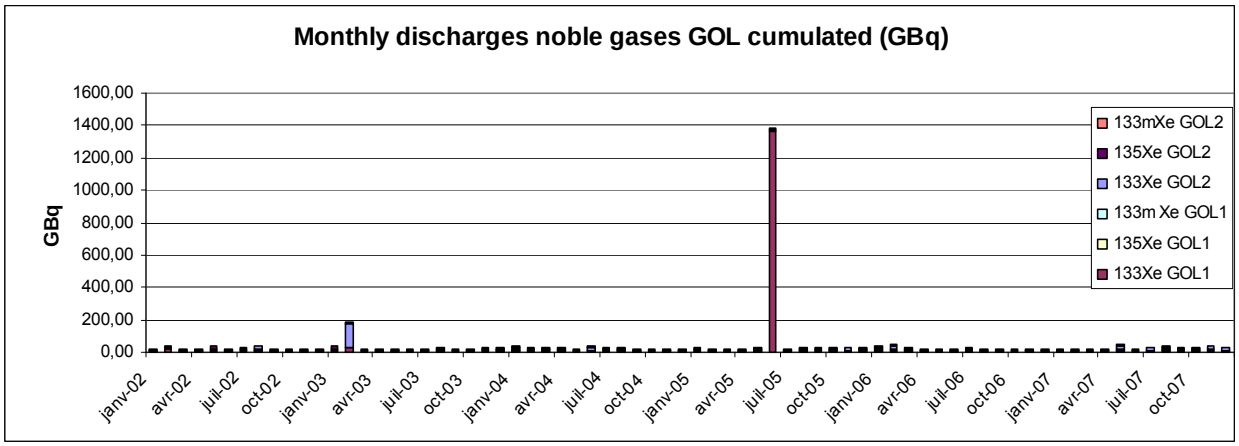


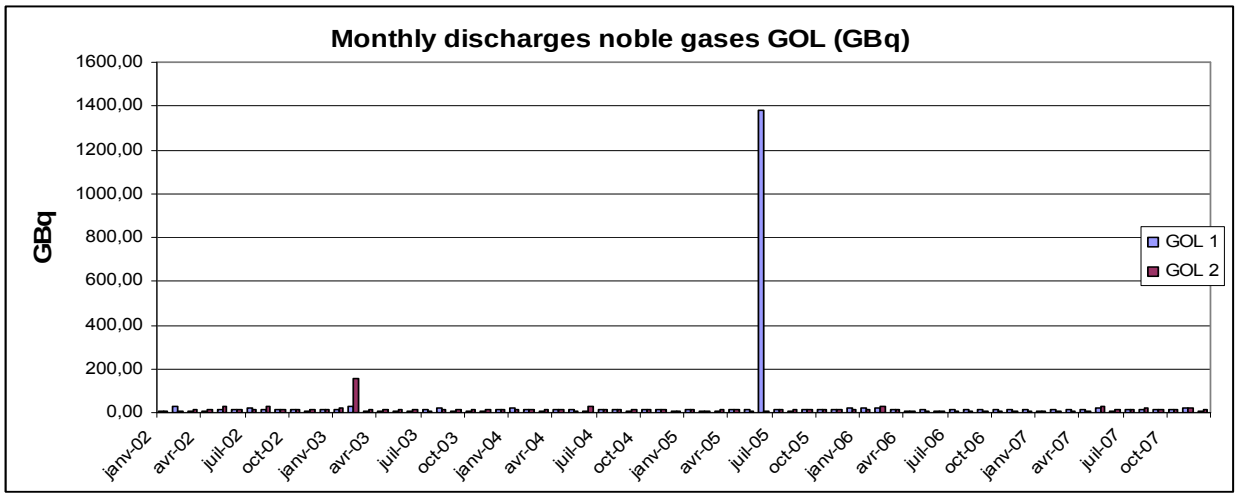


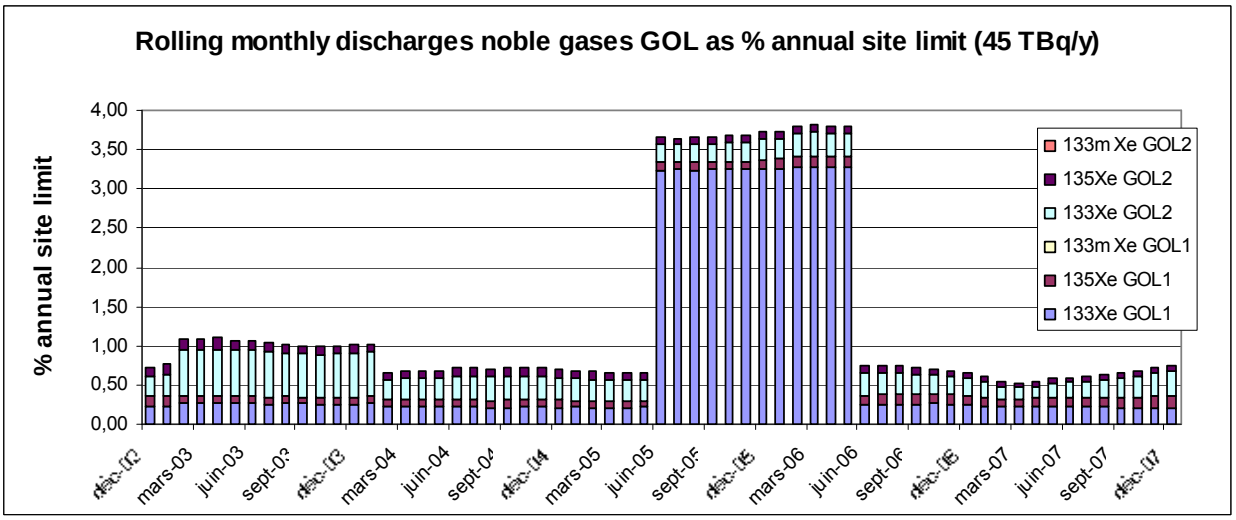
Appendix A-42: Monthly discharges noble gases Paluel, total activity (GBq) per stack.



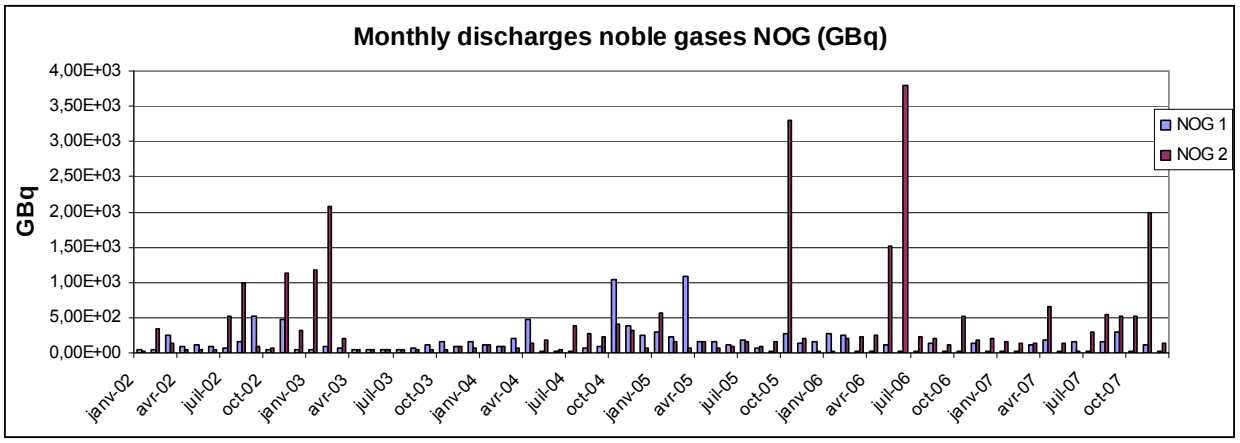
Appendix A-43: Monthly and rolling monthly discharges noble gases Golfech, total activity (GBq) and as percentage of annual site discharge limit.

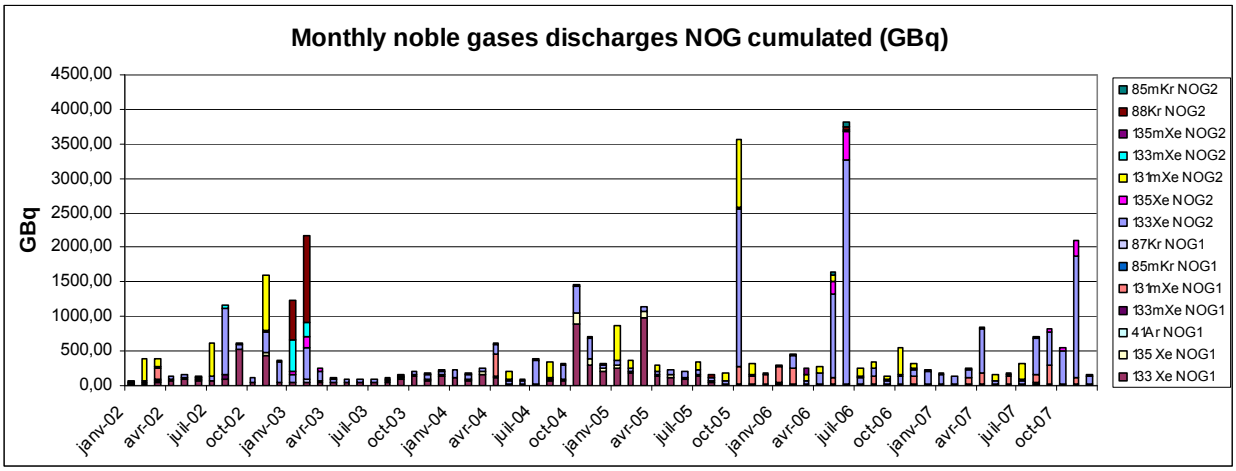


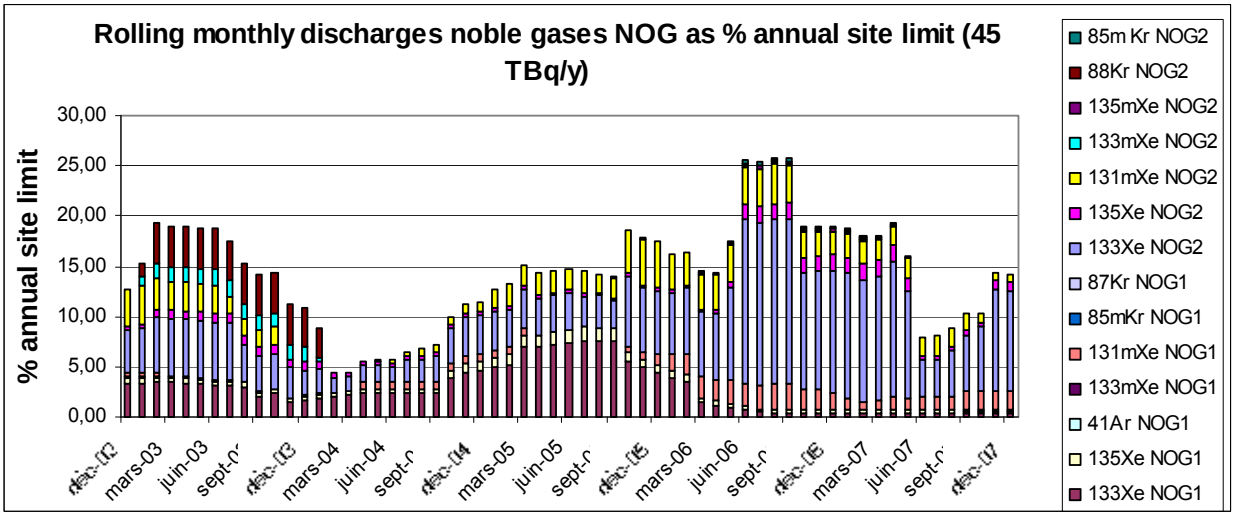




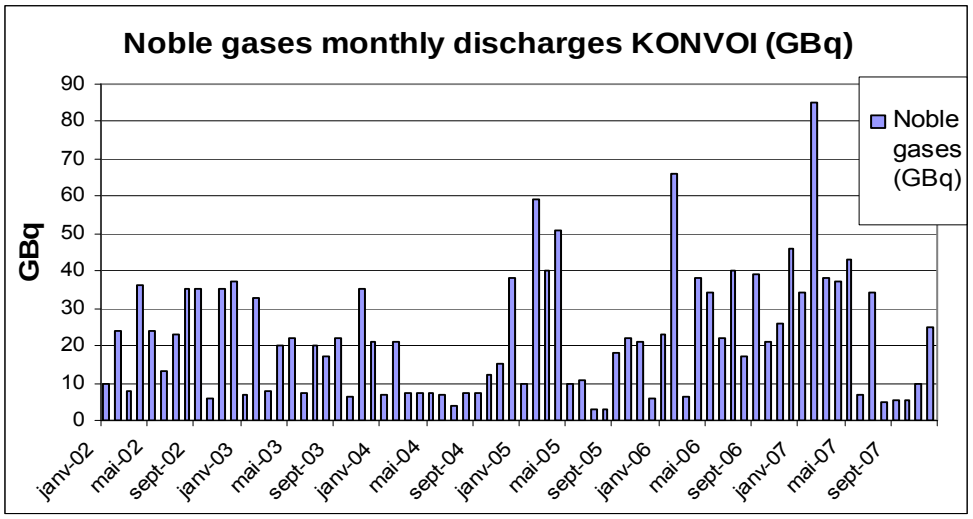
Appendix A-44: Monthly and rolling monthly discharges noble gases Nogent, total activity (GBq) and as percentage of annual site discharge limit.

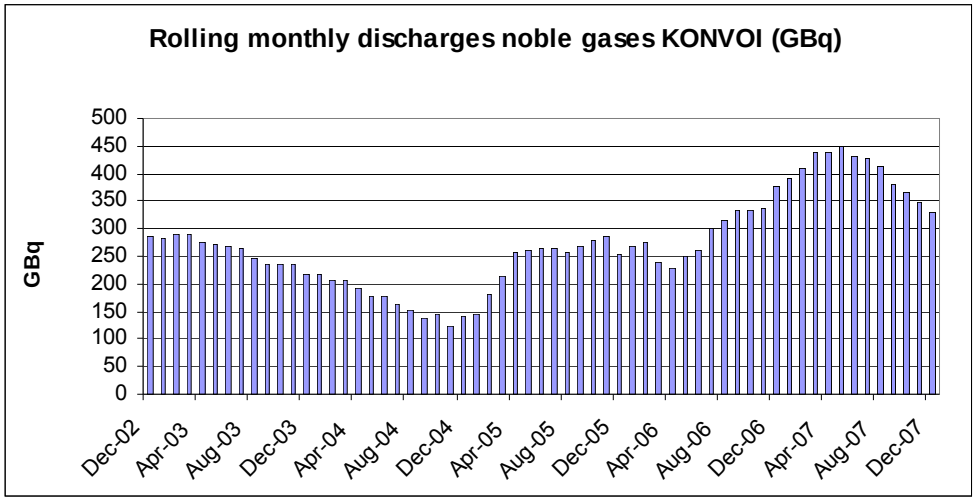




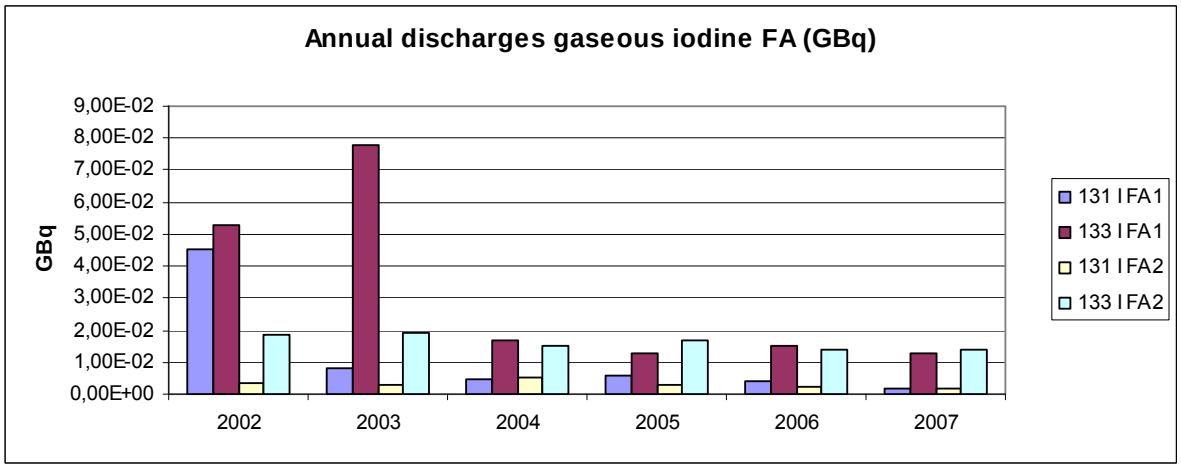


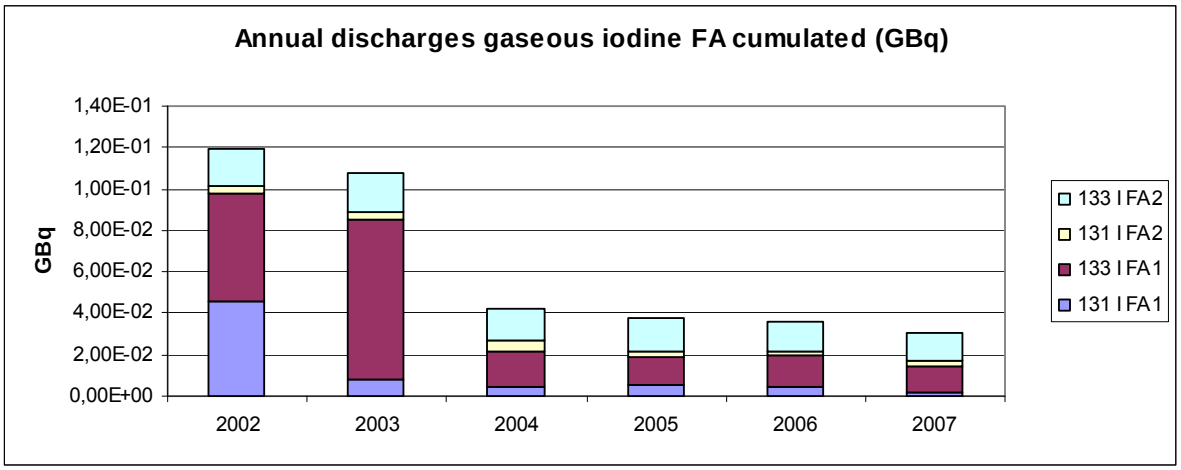
Appendix A-45: Monthly and rolling monthly discharges noble gases ISAR 2 KONVOI, total activity (GBq).

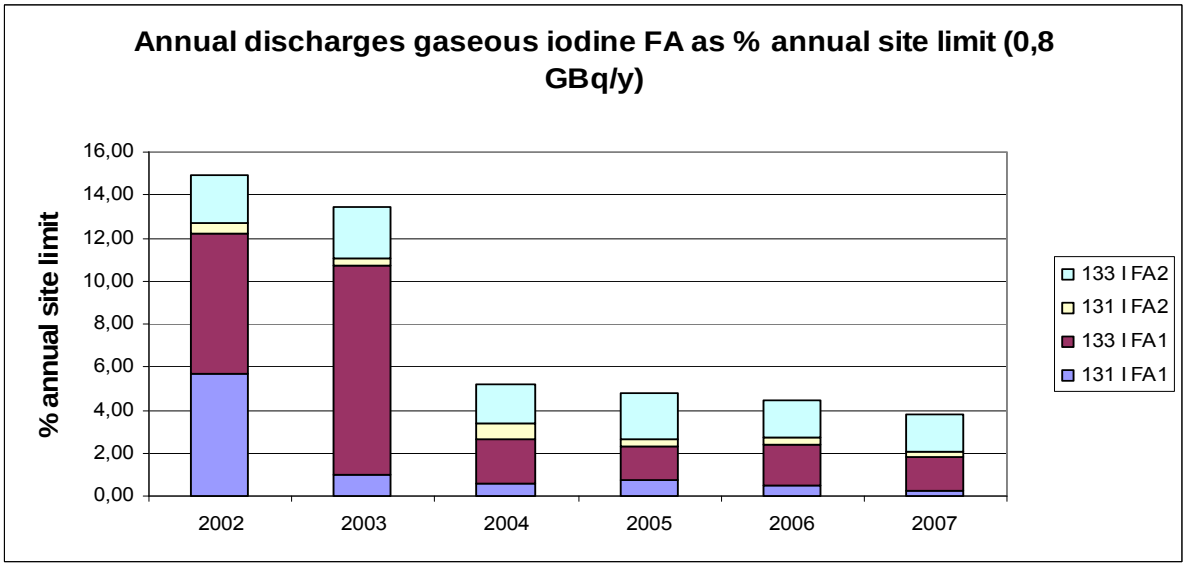




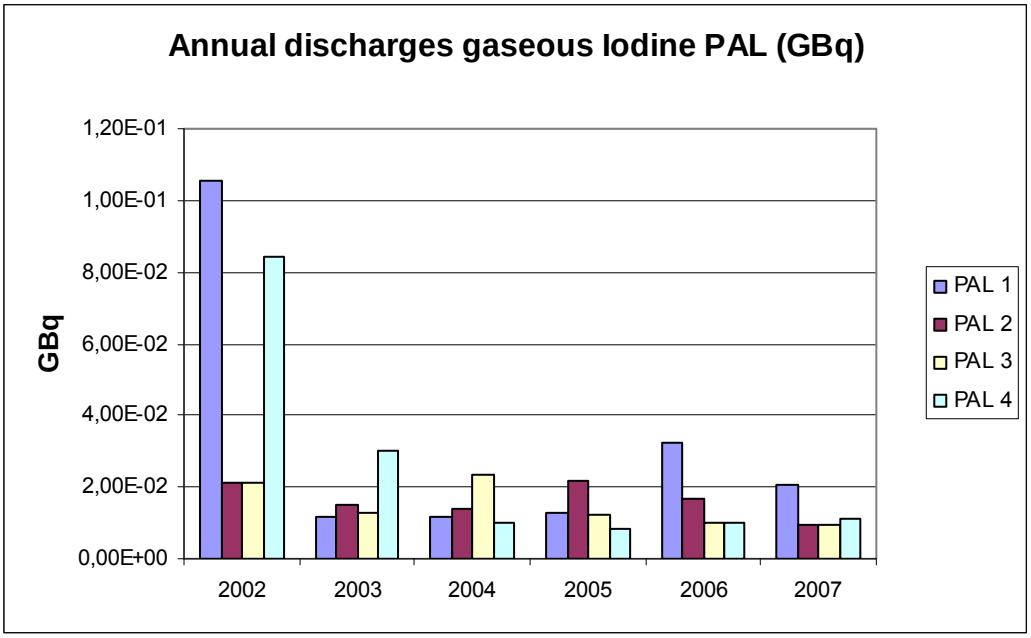
Appendix A-46: Annual discharges gaseous iodine Flamanville, total activity (GBq) and as percentage of annual site discharge limit.

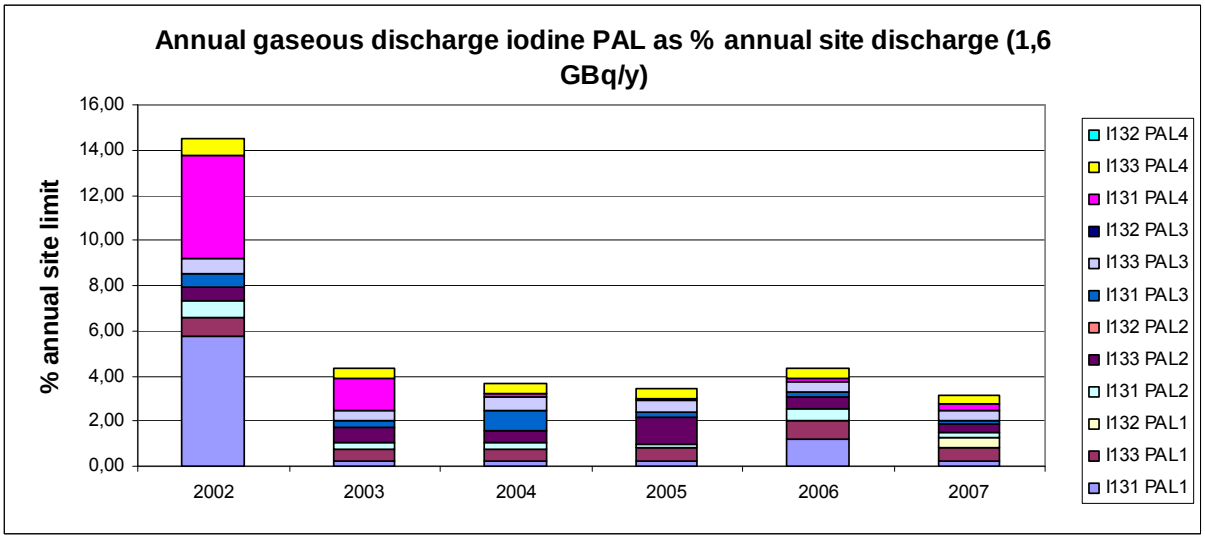




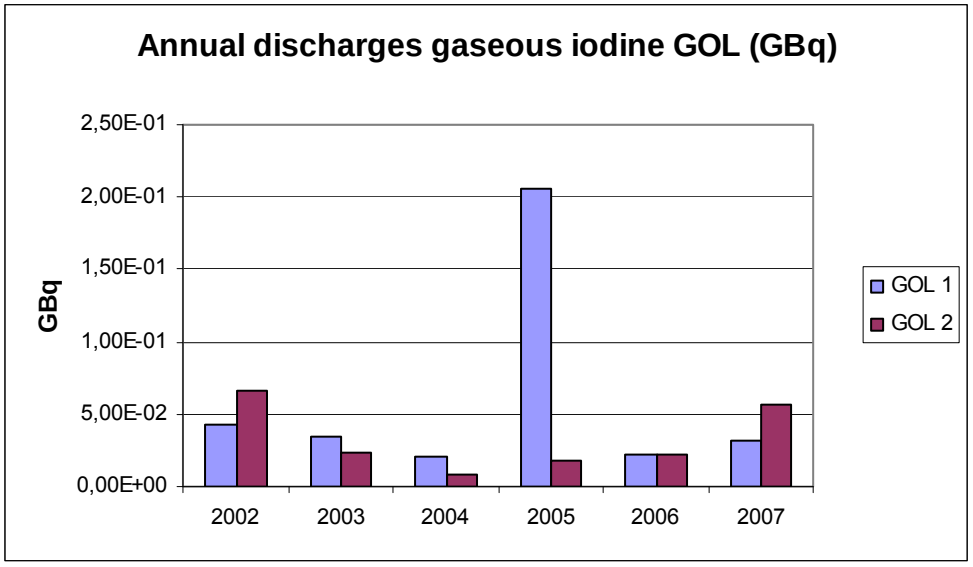


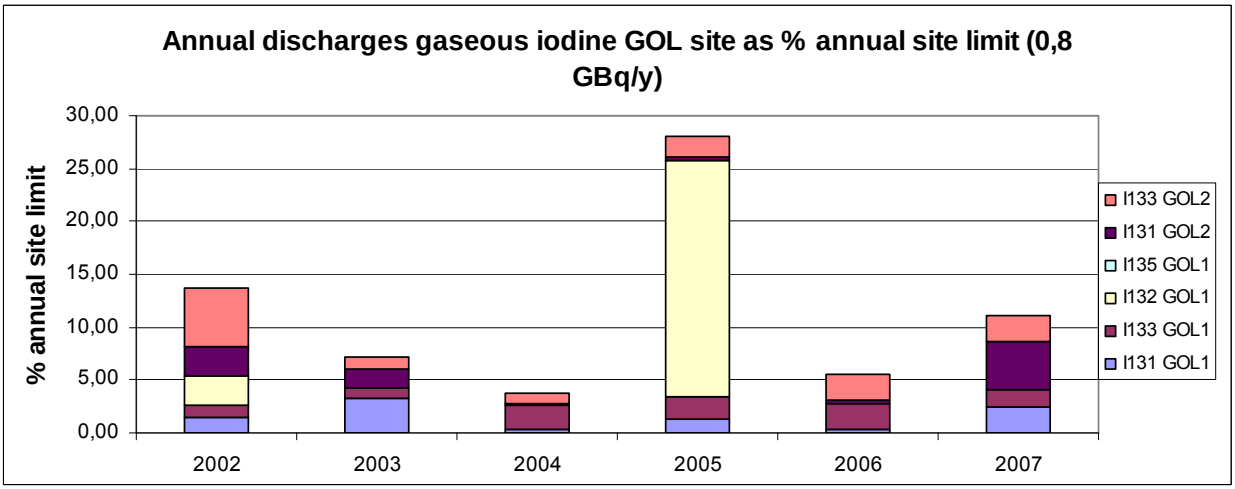
Appendix A-47: Annual discharges gaseous iodine Paluel, total activity (GBq) and as percentage of annual site discharge limit.



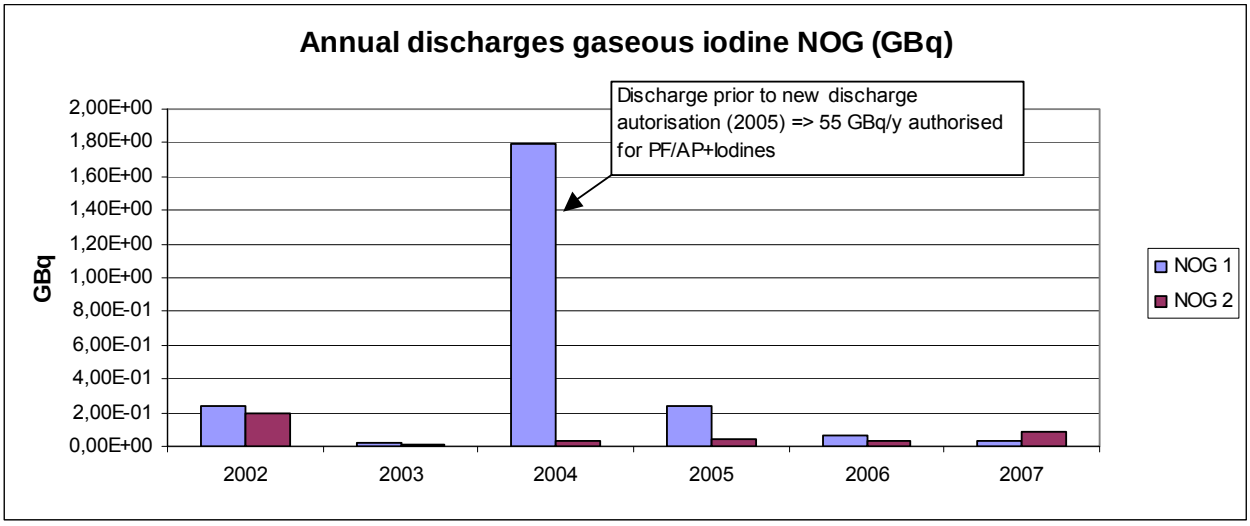


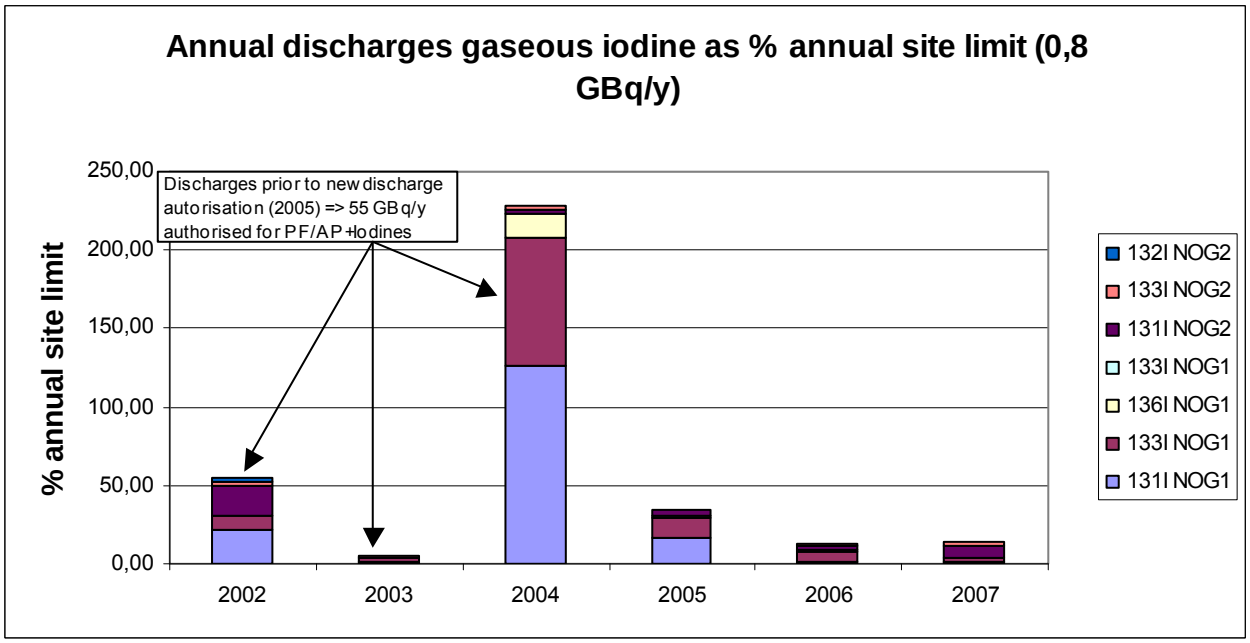
Appendix A-48: Annual discharges gaseous iodine Golfech, total activity (GBq) and as percentage of annual site discharge limit.



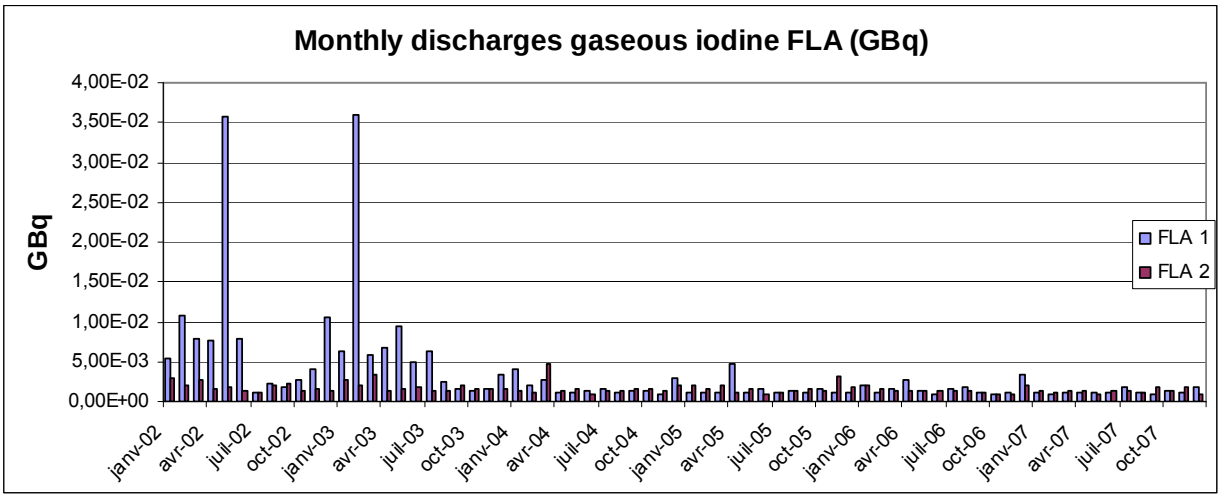


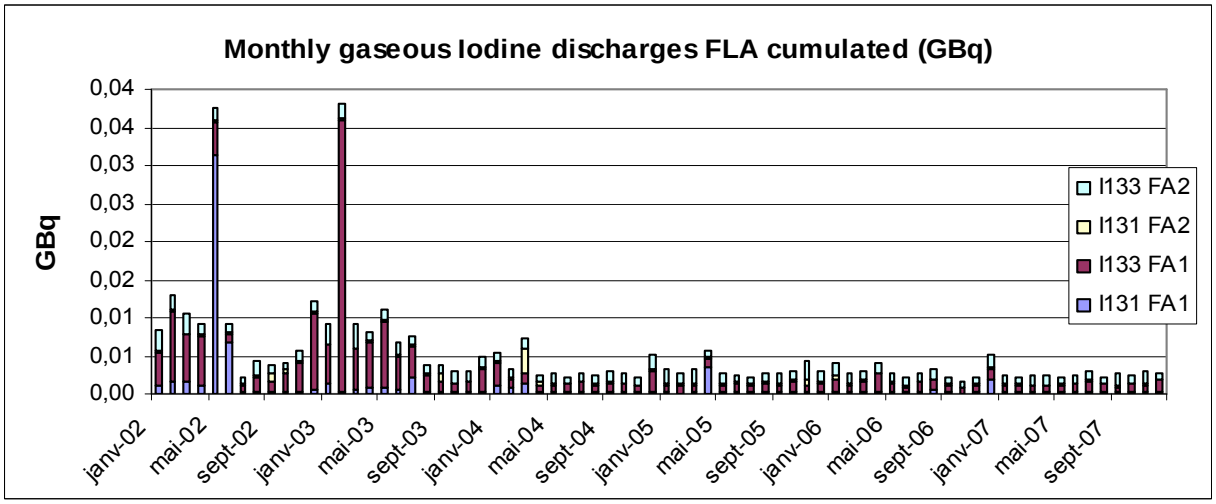
Appendix A-49: Annual discharges gaseous iodine Nogent, total activity (GBq) and as percentage of annual site discharge limit.

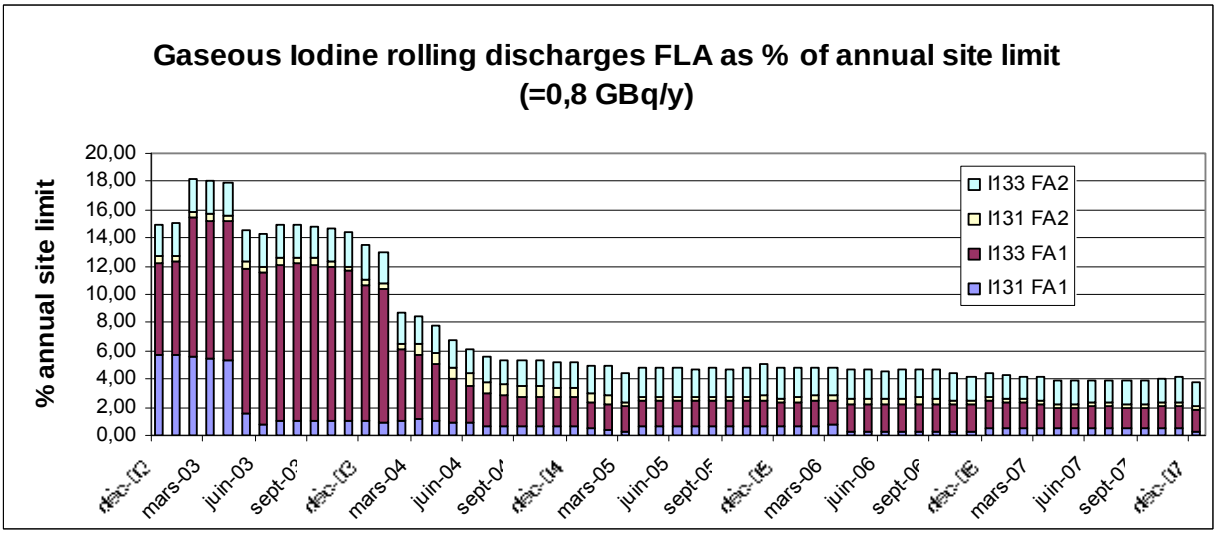




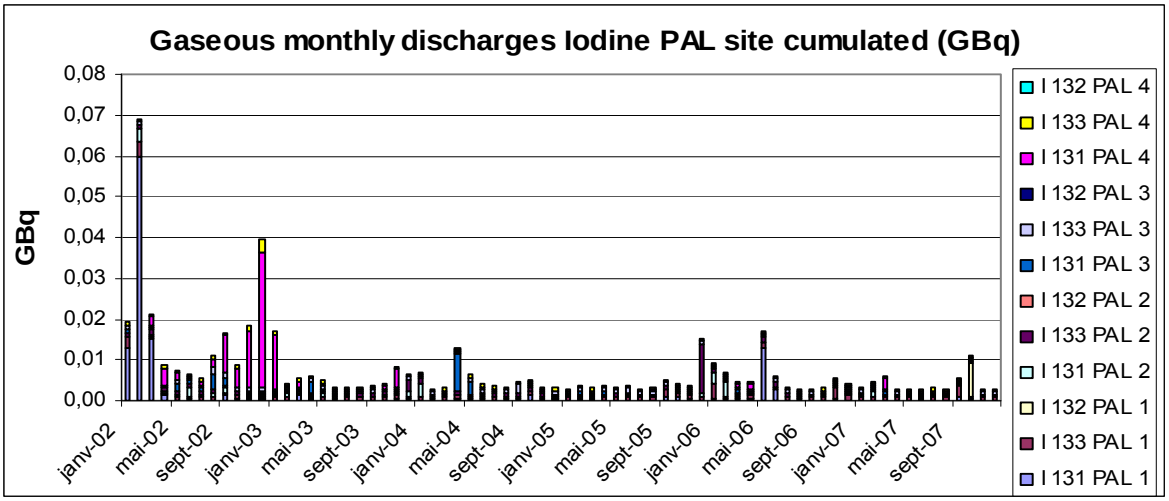
Appendix A-50: Monthly and rolling monthly discharges gaseous iodine Flamanville, total activity (GBq) and as percentage of annual site discharge limit.

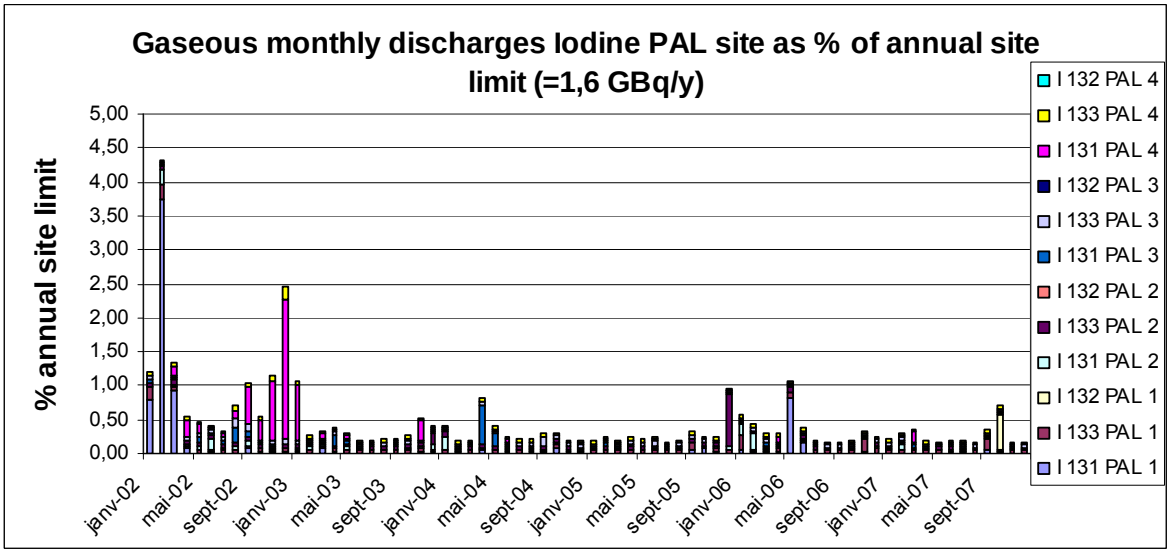


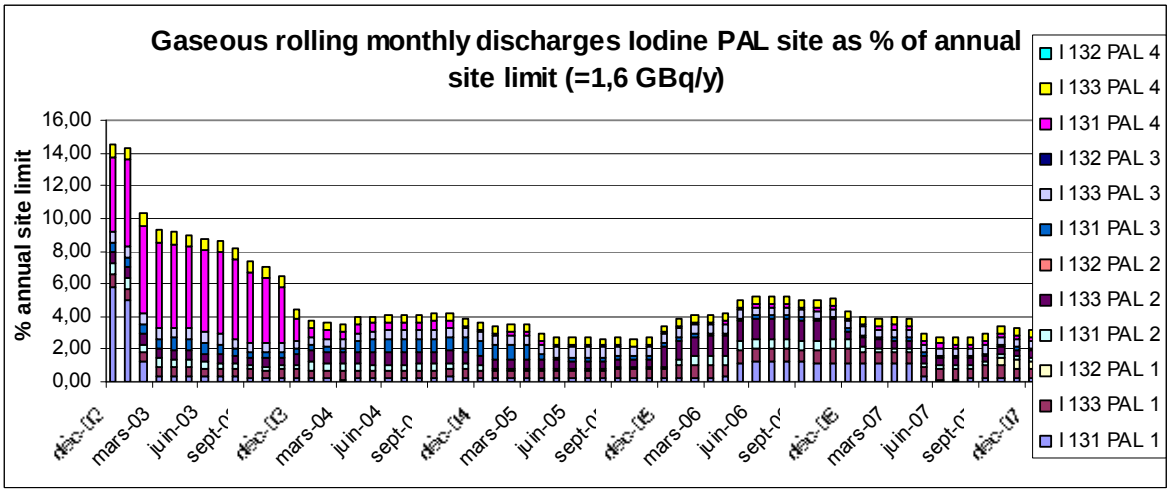




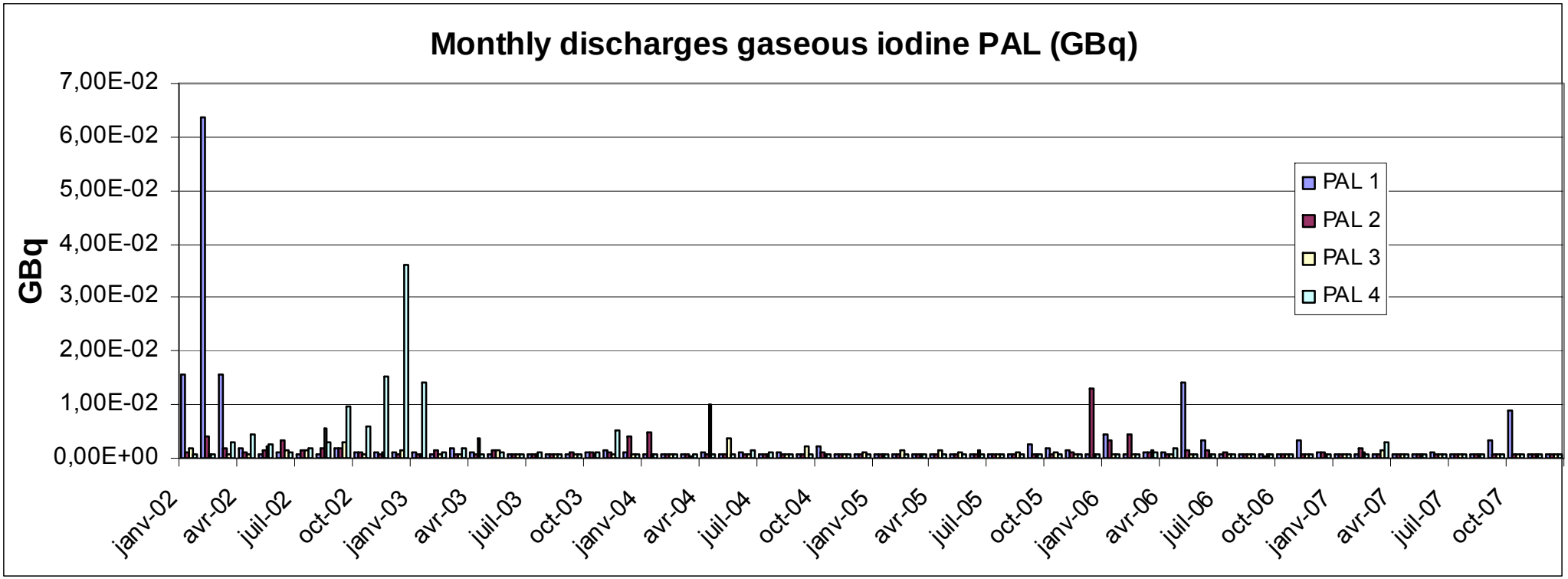
Appendix A-51: Monthly and rolling monthly discharges gaseous iodine Paluel, total activity (GBq) and as percentage of annual site discharge limit.



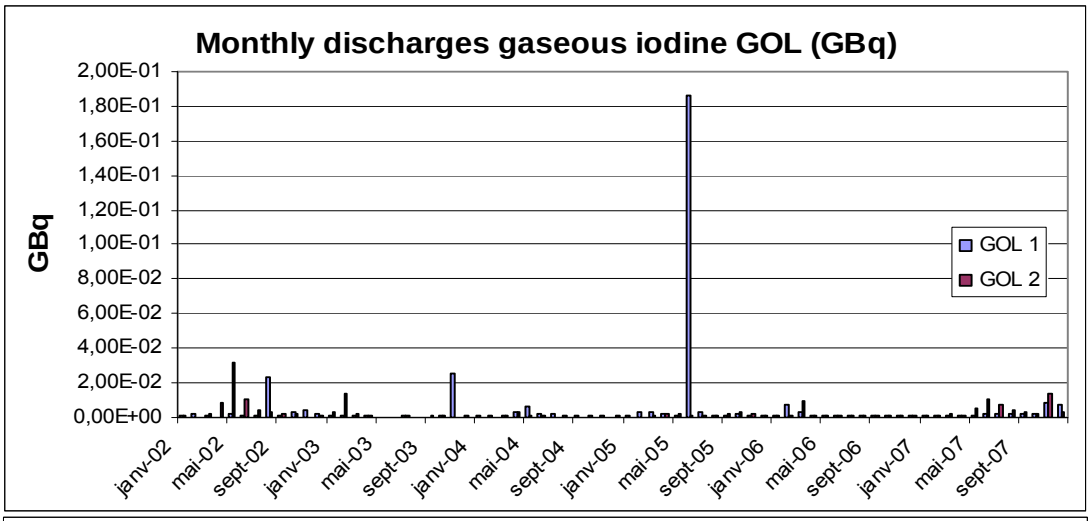


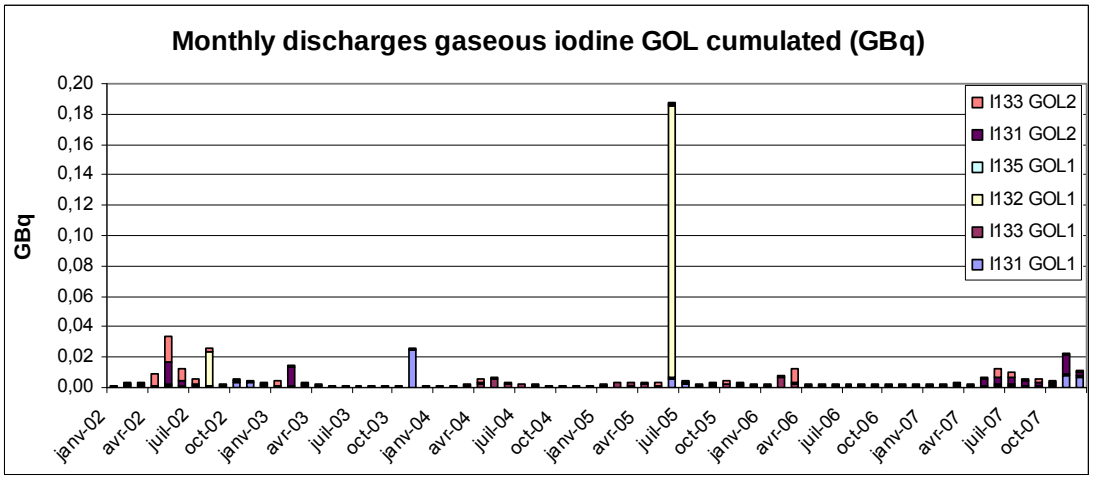


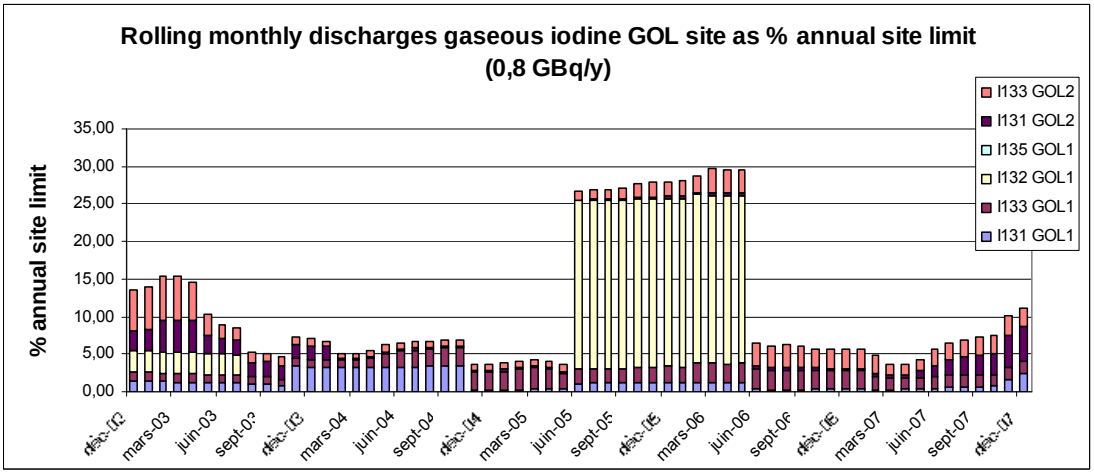
Appendix A-52: Monthly discharges gaseous iodine Paluel, total activity (GBq) per stack.



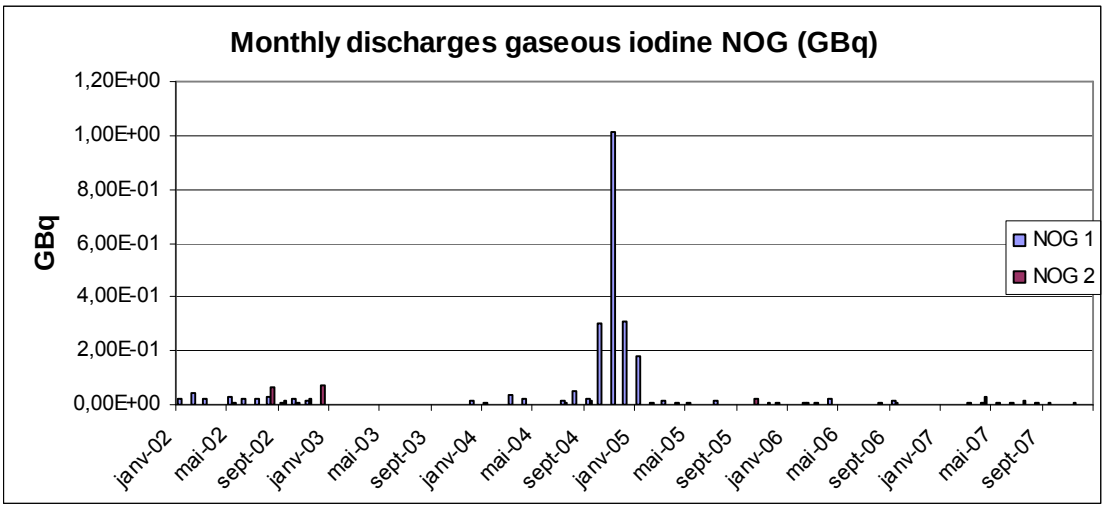
Appendix A-53: Monthly and rolling monthly discharges gaseous iodine Golfech, total activity (GBq) and as percentage of annual site discharge limit.

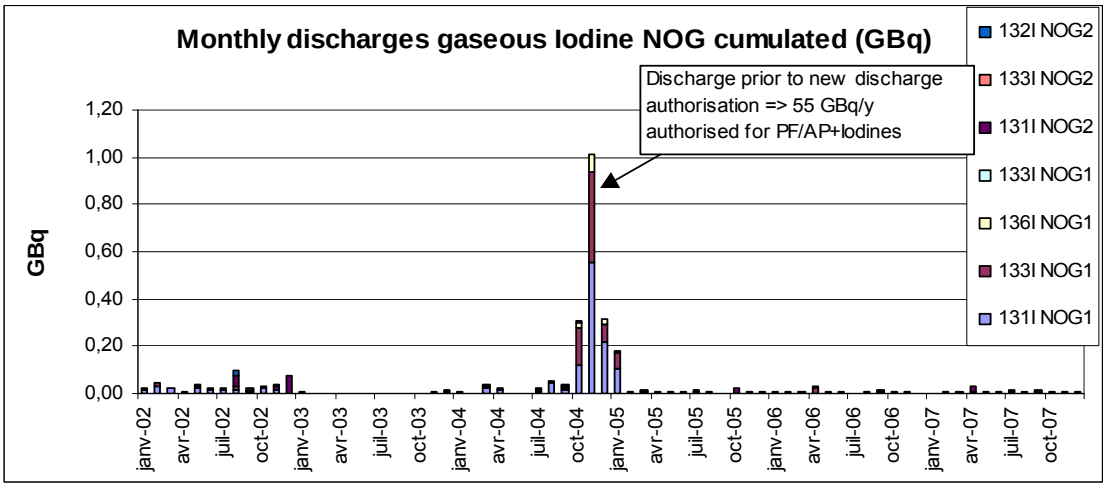


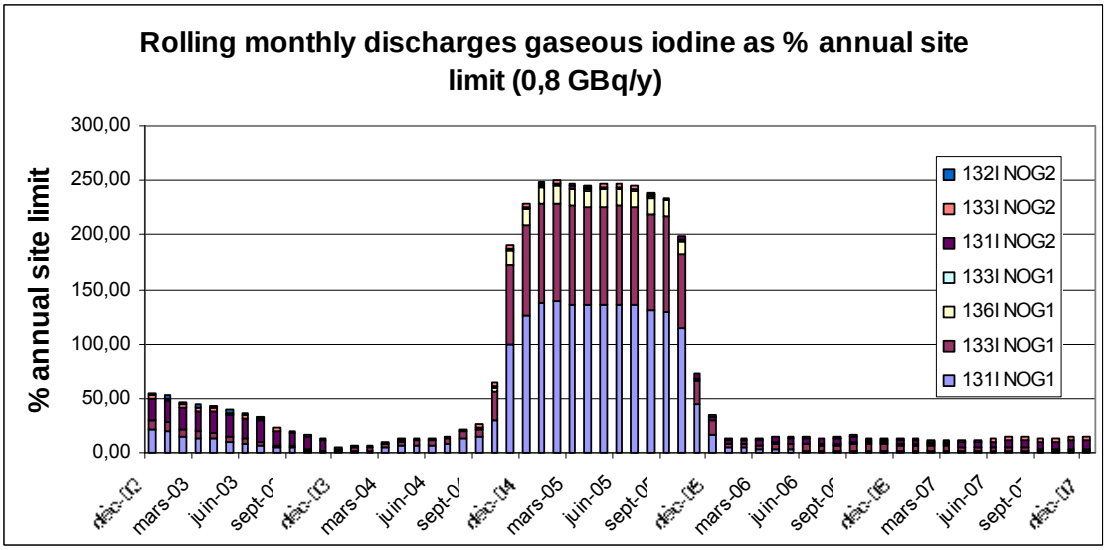




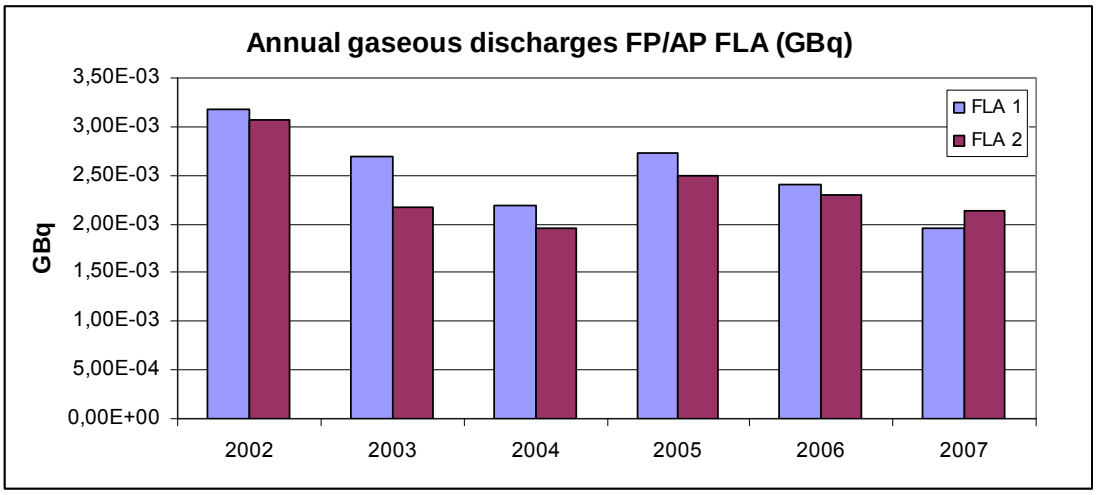
Appendix A-54: Monthly and rolling monthly discharges gaseous iodine Nogent, total activity (GBq) and as percentage of annual site discharge limit.

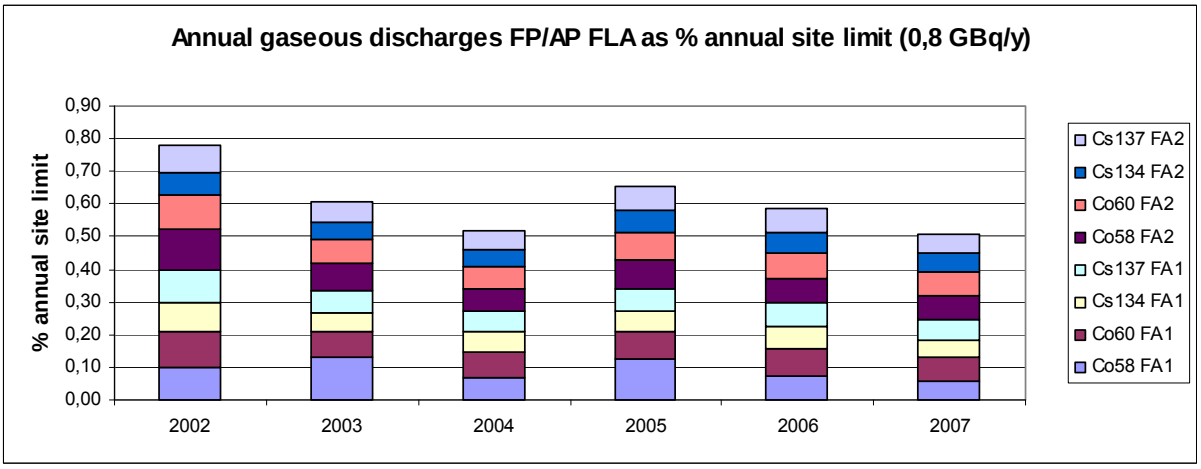




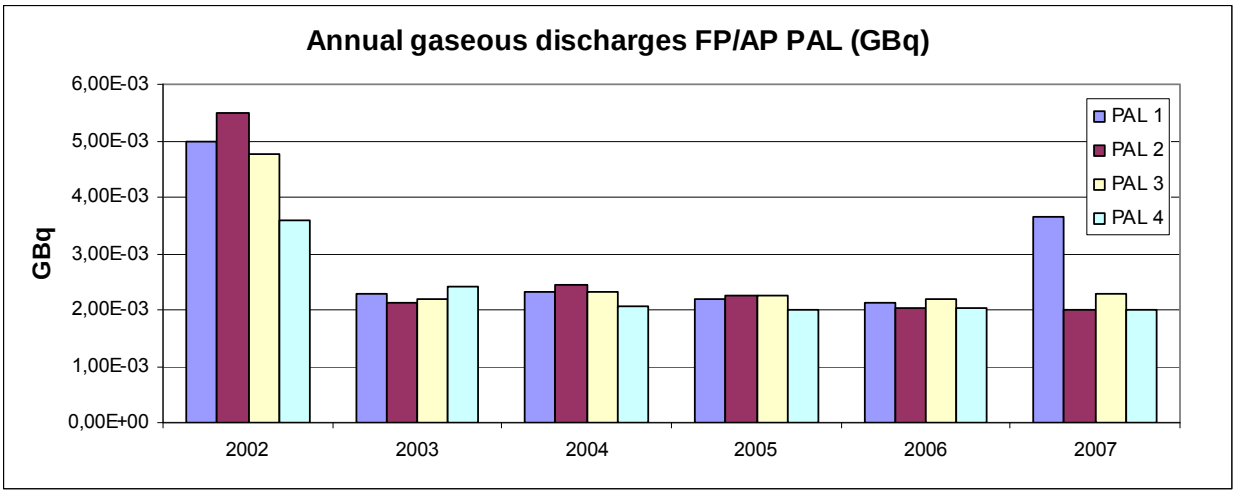


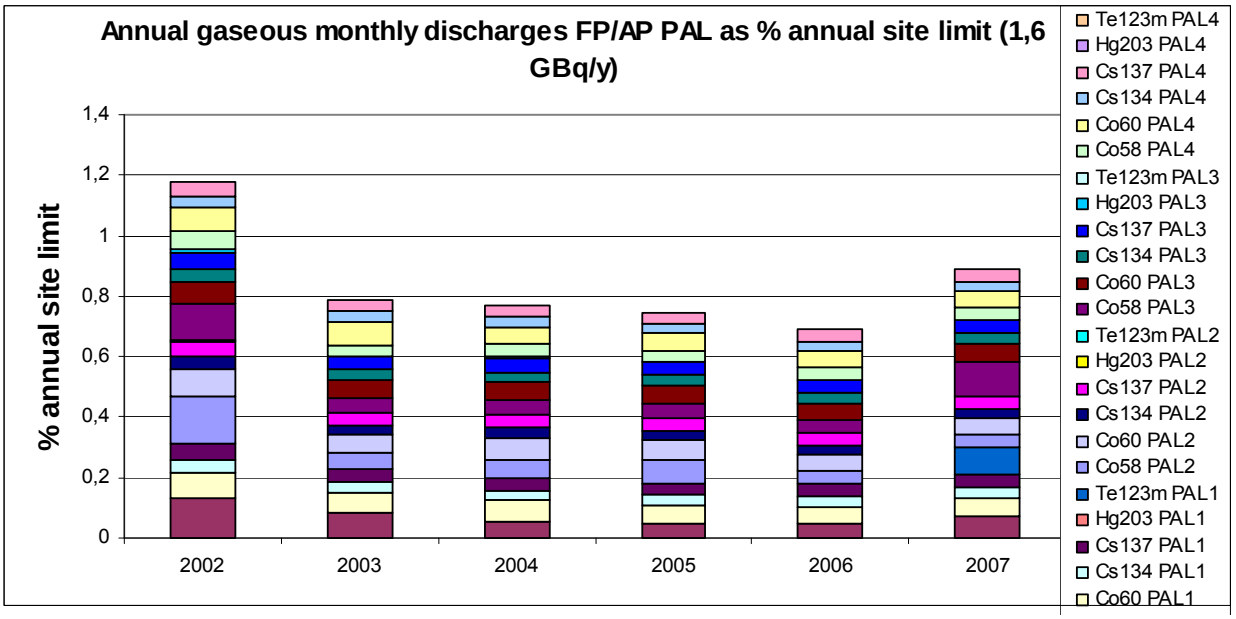
Appendix A-55: Annual discharges gaseous fission and activation products Flamanville, total activity (GBq) and as percentage of annual site discharge limit.



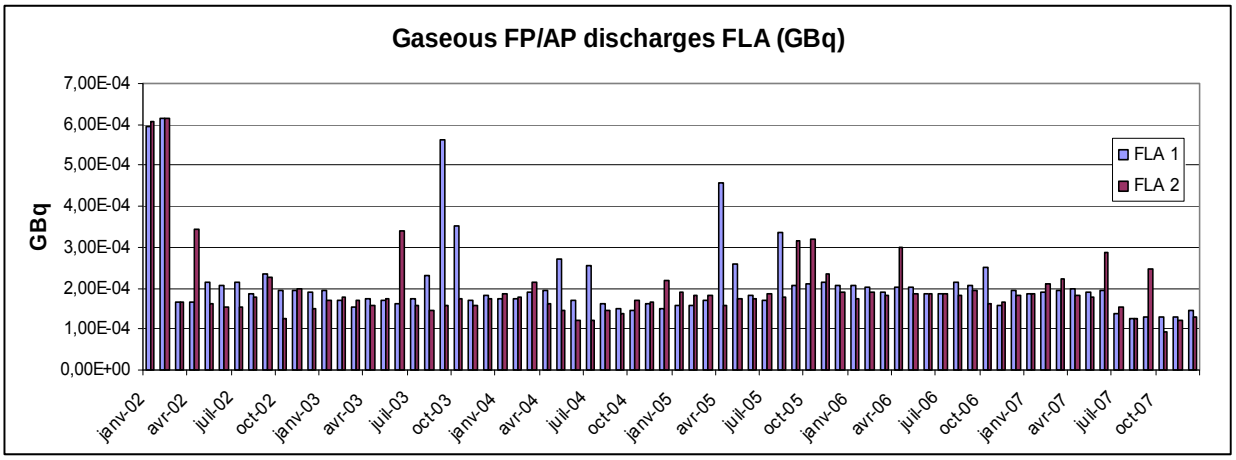


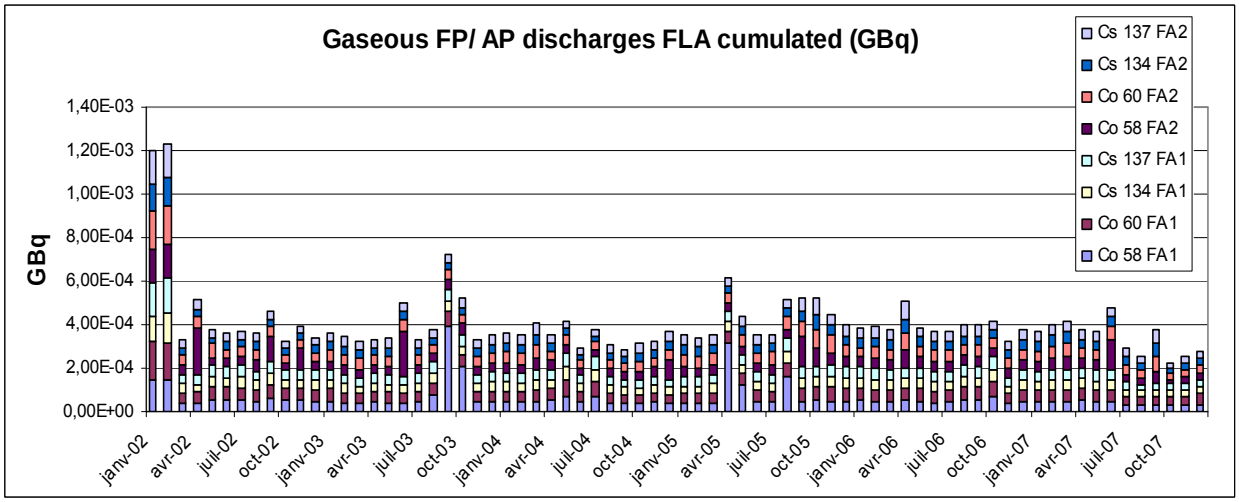
Appendix A-56: Annual discharges gaseous fission and activation products Paluel, total activity (GBq) and as percentage of annual site discharge limit.

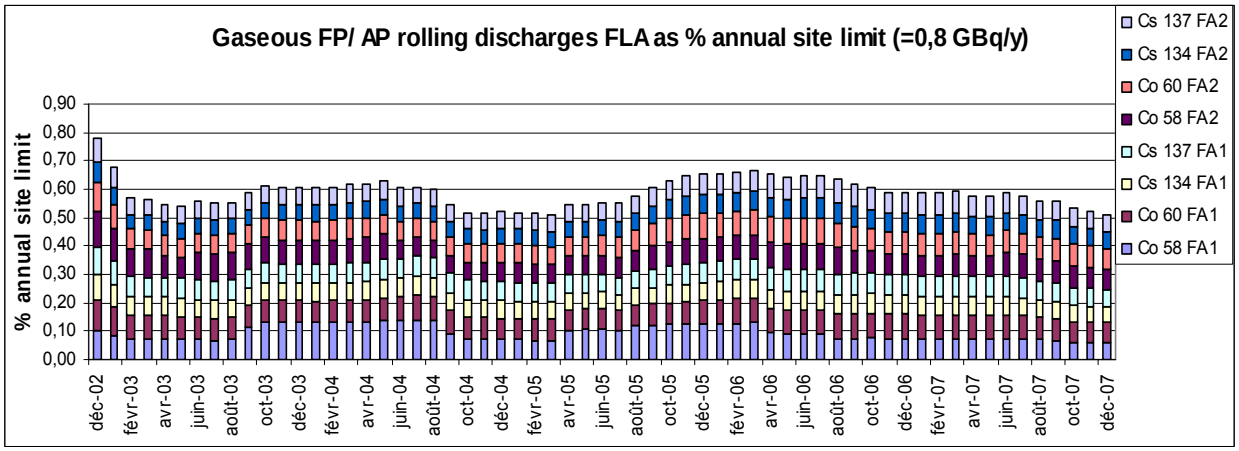




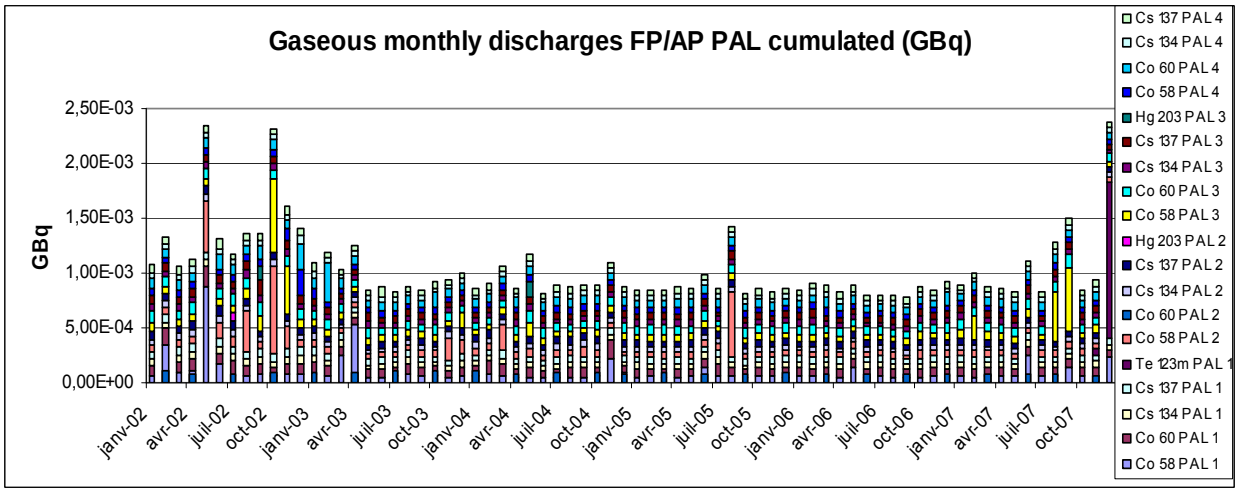
Appendix A-57: Monthly and rolling monthly discharges gaseous fission and activation products Flamanville, total activity (GBq) and as percentage of annual site discharge limit.

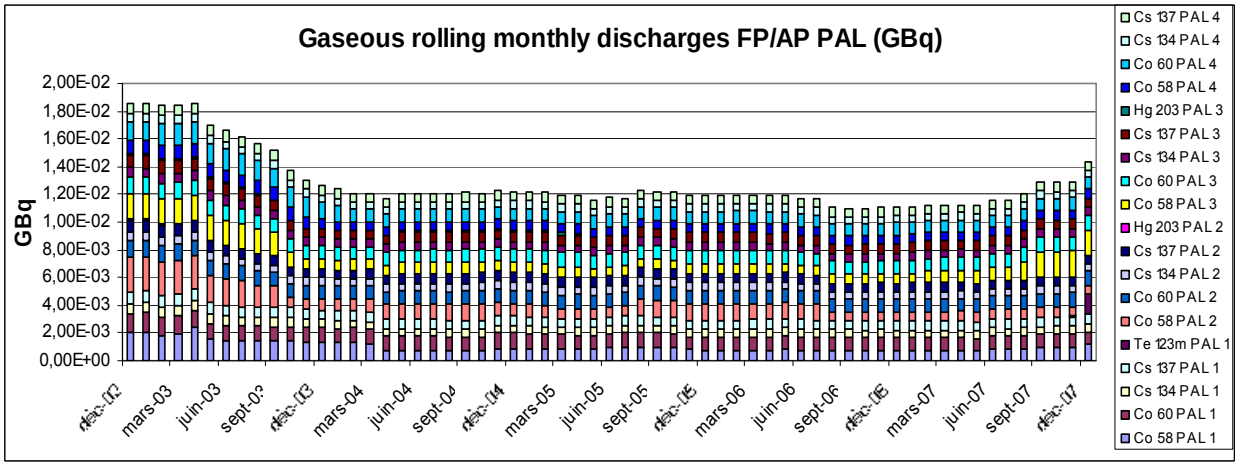


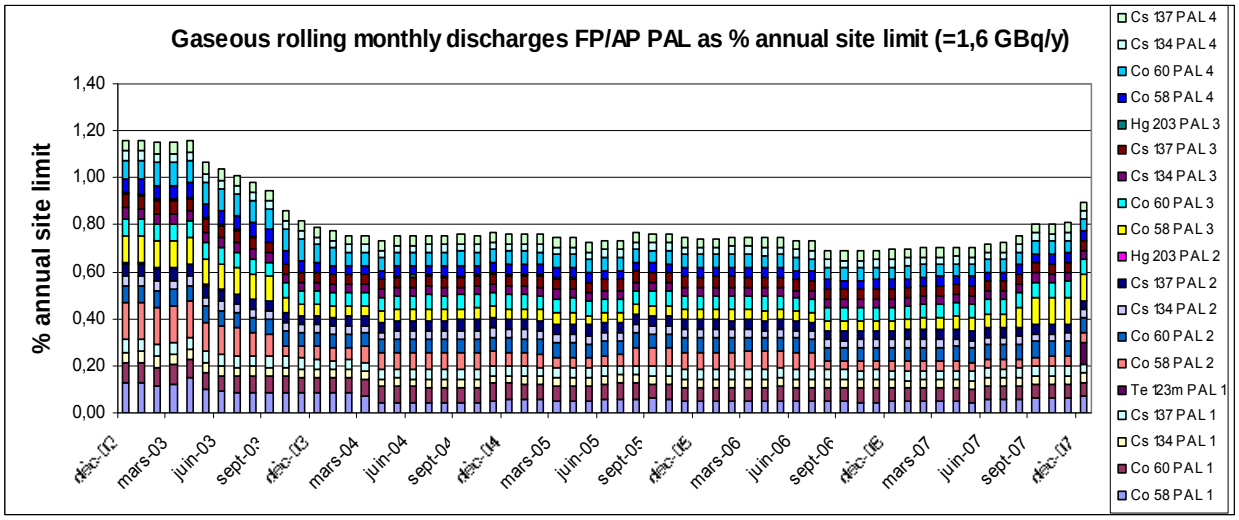




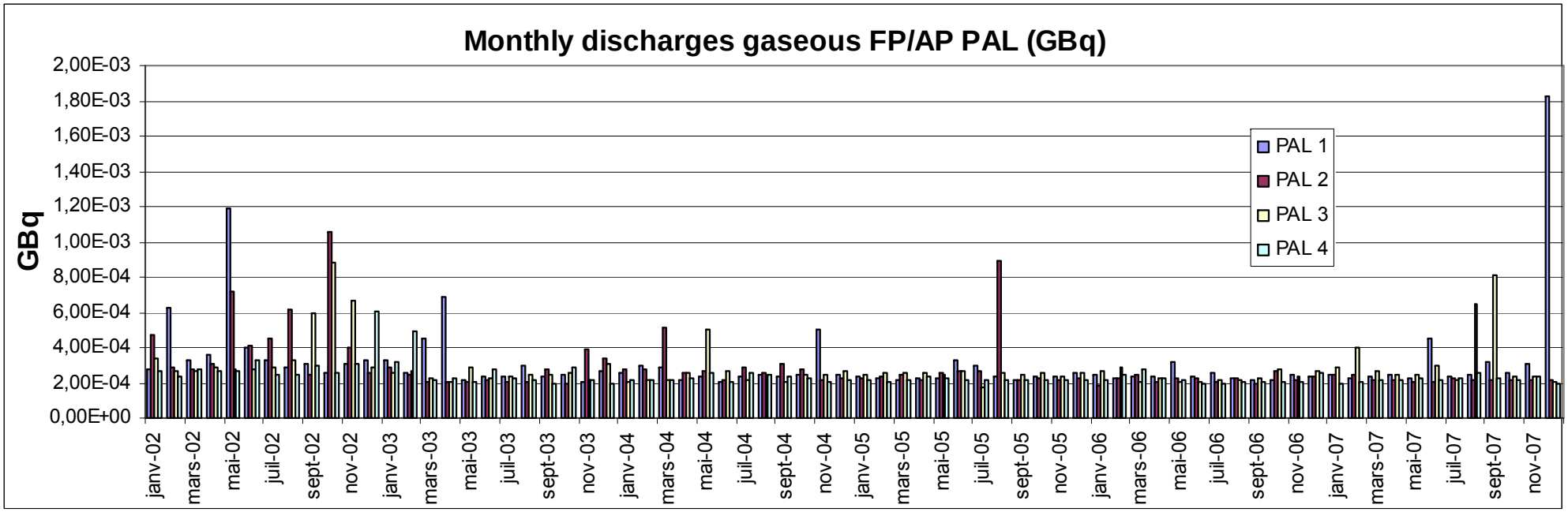
Appendix A-58: Monthly and rolling monthly discharges gaseous fission and activation products Paluel, total activity (GBq) and as percentage of annual site discharge limit.







Appendix A-59: Monthly discharges gaseous fission and activation products Paluel, total activity (GBq) per stack.



Appendix B-1: Summary of the proposed expected monthly value and proposed annual limit for the EPR liquid discharges

Radionuclide		Expected performance without contingency	Proposed annual limit	Monthly discharge without contingency	Maximum monthly discharge to be expected
Liquids	Tritium	52 TBq/y	75 TBq/y	25% of expected perf without contingency = 13 TBq/month	25% annual site limit = 18.75 TBq/month => contingency = 5.75 TBq/month
		The headroom is due to the fuel management of the site which has not been decided on yet for the EPR, and potential need to discharge of tritium produced in previous year that was not discharged as produced			
	C-14	23 GBq/y	95 GBq/y	It is expected that the behaviour of liquid C-14 will be similar to that of liquid H3 and therefore 25% of expected perf without contingency = 5.75 GBq/month	It is expected that the behaviour of liquid C-14 will be similar to that of liquid H-3 and therefore 25% of annual site limit = 24 GBq/month => contingency = 18 GBq/month
		Perf estimated considering 4% C-14 discharges as liquid. No operational feedback, Penly's 1st results in 09/08 => about 10 GBq/y	Limit estimated considering 20% C-14 discharges as liquid		
	Iodine isotopes	7 MBq/y	50 MBq/y	0.7 MBq/month	50 MBq/month. Contingency if fuel leak associated with fault of treatment systems
		Contingency is a combination of leaking fuel pin and unavailability of one treatment system			
	FP/AP	0.6 GBq/y	10 GBq/y	Up to 0.3 GBq/month during shutdown period (with no fuel leaks). Shutdown periods account for about 6months' worth of discharge.	10 GBq/month (see St Alban OEF). Contingency: shutdown and fuel failure + unavailability of storage tanks (requiring discharge of effluent with no preliminary decay)=> contingency is 95% of annual limit
		Discharges of FP/AP have decreased recently and most sites are around 0.2/0.3GBq/y. Contingency is simultaneous fault of treatment system and contamination of a storage tank =>effluent needs to be discharged before RN can decay. Discharges of FP/AP of the EPR expected to be higher as shutdown period much shorter than on 1300 MW(e)			

Appendix B-2: Summary of the proposed expected monthly value and proposed annual limit for the EPR gaseous discharges

Radionuclide		Expected performance without contingency	Proposed annual limit	Monthly discharge without contingency	Maximum monthly discharge to be expected
Gaseous	Tritium	0.5 TBq/y	3 TBq/y	50 GBq/ month. No major contingency identified	300 GBq/month seems reasonable as discharges are proportional to production
		No obvious contingency to explain headroom. Can be justified by fact that no OEF available, TEP [CSTS] management is different on EPR, and need to account for potential contamination of storage tanks that remains for a long time			
	C-14	350 GBq/y	700 GBq/y	100 GBq/quarter. No major contingency identified	300 GBq/quarter seems reasonable as discharges are proportional to production
		No OEF available. No major contingency expected for the EPR as continuous discharges. Contingency for 1300 MW(e) reactors is unit shutdown where all limit could be discharged in a month. In the year where no shutdown, gaseous C-14 discharges should be almost inexistent. In the EPR, uncertainties on split solid/liquid/gaseous discharges and N_2 concentration of primary circuit.			
	Noble gases	0.8 TBq/y	22.5 TBq/y	0.4 TBq/month if shutdown and no fuel leak. Shutdown periods account for about 6months' worth of discharge.	5 TBq/month if shutdown and fuel leaks. Contingency: shutdown and fuel failure
		Contingency is fuel leak and TEG [GWPS] tank discharged too early (operational error). In case of fuel leaks, discharges are about twice the discharged without leaks. No existing treatment systems if operating contingency occurs.			
	Iodine isotopes	50 MBq/y	400 MBq/y	Proposed 20 MBq/month	300 MBq/month. Contingency: fuel leaks and shutdown, massive influence on discharge. Halogens released during the TEG [GWPS] blowdown during shutdown => some is released straight away, some is released 40 days later
		Contingency is fuel leaks. Small fuel leaks account for about 10 times discharge without fuel leaks. Annual limit is the most threatened out of all limits, only little room for operational contingencies.			
	FP/AP	4 MBq/y	120 MBq/y	0.8 MBq/month	50% annual limit = 60 MBq/y. Maximum discharge potentially heavily impacted by one-off high discharge
		Principally LOD measures. Short term discharges may have a major impact on annual discharges. Large variability of OEF of the current 1300 MW(e) fleet not completely understood (currently under investigation)			

SUB-CHAPTER 6.3 – REFERENCES

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

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

1. INTRODUCTION

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

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

[Ref-3] GDA UK EPR - BAT Demonstration. UKEPR-0011-001 Issue 06. EDF/AREVA. August 2012. (E)

2. SPENT NUCLEAR FUEL

[Ref-1] Solid Radioactive Waste Strategy Report (SRWSR). NESH-G/2008/en/0123 Revision A. AREVA NP. November 2008. (E)

3. SOLID RADIOACTIVE WASTE

3.1. EPR ANNUAL ESTIMATED PRODUCTION OF RAW WASTE

[Ref-1] Projected assessment of solid radioactive waste from the EPR. ECMT050107 Revision A1. EDF. November 2009. (E)

ECMT050107 Revision A1 is the English translation of ECMT050107 Revision A.

[Ref-2] B Lantes. EPR waste arising over the operating life. D450711001253 Version 0. EDF. March 2011. (E)

3.2. CHARACTERISTICS OF PACKAGED SOLID WASTE FOR THE UK EPR REFERENCE CASE

[Ref-1] System Design Manual – Solid Waste Treatment System (TES [SWTS]) – Filter changing equipment TES11, P2 – System operation. SFLEZM200118 Revision B. SOFINEL. September 2006. (E)

[Ref-2] System Design Manual – Solid Waste Treatment System (TES [SWTS]) – Filter changing equipment TES11, P3 – Sizing of the system and its components. SFLEZM200119 Revision B. SOFINEL. September 2006. (E)

[Ref-3] System Design Manual – Solid Waste Treatment System (TES [SWTS]) – Transfer of the spent resins (TES21, TES31), P2 – System operation. SFL-EZS030040 Revision D. SOFINEL. March 2007. (E)

[Ref-4] System Design Manual – Solid Waste Treatment System (TES [SWTS]) – Transfer of the spent resins (TES21, TES31), P3 – Sizing of the system and its components. SFL-EZS030041 Revision D. SOFINEL. March 2007. (E)

[Ref-5] System Design Manual – Solid Waste Treatment System (TES [SWTS]) – Transfer of the spent resins (TES21, TES31), P1. SFLEZS030039 Revision D. SOFINEL. March 2007. (E)

[Ref-6] System Design Manual – Solid Waste Treatment System (TES [SWTS]) – Transfer of the spent resins (TES21, TES31), P4 – Flow diagrams. SFL-EZS030042 Revision D. SOFINEL. March 2007. (E)

[Ref-7] System Design Manual – Solid Waste Treatment System (TES [SWTS]) – Transfer of the spent resins (TES21, TES31), P4.1 – Simplified flow diagrams. EZS/2006/en/0019 Revision A. SOFINEL. March 2007. (E)

[Ref-8] System Design Manual – Solid Waste Treatment System (TES [SWTS]) – Transfer of the spent resins (TES21, TES31), P4.2 – Detailed flow diagrams. EZS/2006/en/0020 Revision B. SOFINEL. March 2007. (E)

3.2.2. Quantification and radioactive characterisation of EPR waste streams

[Ref-1] Decontamination Processes and Techniques for the UKEPR. UKEPR-0017-001 Issue 00. EDF/AREVA. March 2011. (E)

3.2.3. Quantification of nuclides and declaration of packages radioactivity content

[Ref-1] Nuclear Energy - Nuclear Fuel Technology - The Scaling Factor method to determine the radioactivity of low and intermediate level radioactive waste packages generated at nuclear power plant. ISO/DIS 21238. (E)

3.3. CHARACTERISTICS OF PACKAGED SOLID WASTE FOR OPTIONS TO THE REFERENCE CASE

[Ref-1] Solid Radioactive Waste Strategy Report (SRWSR). NESH-G/2008/en/0123 Revision A. AREVA NP. November 2008. (E)

6. LIQUID RADIOACTIVE EFFLUENT DISCHARGES

6.1. EURATOM RECOMMENDATION AND FRENCH PRACTICE

[Ref-1] Commission recommendation of 18 December 2003 on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation. C(2003)4832. 2004/2/Euratom. Official Journal of the European Union. 6 January 2004. (E)

6.2. LIQUID DISCHARGES OF TRITIUM

6.2.1. Production

6.2.1.1. Direct sources

[Ref-1] Methods for limiting the production and discharge of tritium for the EPR. ENTERP090190. EDF. August 2009. (E)

ENTERP090190 is the English translation of ENTERP040216 Revision A.

6.2.1.2. Indirect sources

[Ref-1] Methods for limiting the production and discharge of tritium for the EPR. ENTERP090190. EDF. August 2009. (E)

ENTERP090190 is the English translation of ENTERP040216 Revision A.

6.2.1.3. Means of reducing tritium production for EPR

6.2.1.3.1. Burnable poison and Boron concentration

[Ref-1] Methods for limiting the production and discharge of tritium for the EPR. ENTERP090190. EDF. August 2009. (E)

ENTERP090190 is the English translation of ENTERP040216 Revision A.

6.2.1.4. Estimation of the tritium source term

[Ref-1] Analysis of environmental performance in the EPR France project. ECEP050315 Revision A1. EDF. March 2012. (E)

ECEP050315 Revision A1 is the English translation of ECEP050315 Revision A.

6.3. LIQUID DISCHARGES OF CARBON-14

6.3.1. Production

[Ref-1] Zinc Injection Implementation at UK-EPR. ECEF110138 Revision A. EDF. March 2011. (E)

[Ref-2] Zinc Injection claims, arguments and evidences: overall balance for UK-EPR. ECEF110139 Revision A. EDF. March 2011. (E)

6.4. LIQUID DISCHARGES OF OTHER RADIONUCLIDES

[Ref-1] Analysis of environmental performance in the EPR France project. ECEP050315 Revision A1. EDF. March 2012. (E)

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6.4.2. Other liquid discharges of fission and activation products

6.4.2.1. Production and discharge

[Ref-1] Zinc Injection claims, arguments and evidences: overall balance for UK-EPR. ECEF110139 Revision A. EDF. March 2011. (E)

[Ref-2] Source Term: Identification, Quantification and Characterization. ECEF110448 Revision A. EDF. June 2011

[Ref-3] Activity Management at UK-EPR: Auxiliary Systems: System Performances and Control Actions. ECEF110449 Revision A. EDF. June 2012.

6.4.2.3. Liquid fission and activation products quantitative targets

[Ref-1] Analysis of environmental performance in the EPR France project. ECEP050315 Revision A1. EDF. March 2012. (E)

ECEP050315 Revision A1 is the English translation of ECEP050315 Revision A.

7. GASEOUS RADIOACTIVE EFFLUENT DISCHARGES

7.1. EURATOM RECOMMENDATION AND FRENCH PRACTICE

[Ref-1] Commission recommendation of 18 December 2003 on standardised information on radioactive airborne and liquid discharges into the environment from nuclear power reactors and reprocessing plants in normal operation. C(2003)4832, 2004/2/Euratom. Official Journal of the European Union. 6 January 2004. (E)

7.3. GASEOUS DISCHARGES OF CARBON 14

7.3.1. Production and discharge

7.3.1.1. Contribution of the "aeroball" system

[Ref-1] EPR – Production and discharge of C14. ENTERP090183. EDF. August 2009. (E)

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7.3.1.2. Contribution of the reactor pit atmosphere

[Ref-1] EPR – Production and discharge of C14. ENTERP090183. EDF. August 2009. (E)

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7.4. GASEOUS DISCHARGE OF OTHER RADIONUCLIDES

7.4.2. Noble gases discharges

7.4.2.1. Production and discharge

[Ref-1] Analysis of environmental performance in the EPR France project.
ECEP050315 Revision A1. EDF. March 2012. (E)

ECEP050315 Revision A1 is the English translation of ECEP050315 Revision A.

7.4.4. Other gaseous discharge of fission and activation products

7.4.4.1. Production and discharge

[Ref-1] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Part C. Chapter IV.1 Table C-IV.1.1- j - Radionuclides and activities discharged considered in the maximum ("requested limits") gaseous discharge calculations for the EPR unit.(E)

8. CHEMICAL EFFLUENT DISCHARGES

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ECEP050315 Revision A1. EDF. March 2012. (E)

ECEP050315 Revision A1 is the English translation of ECEP050315 Revision A.

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8.1. CHEMICAL DISCHARGES ASSOCIATED WITH RADIOACTIVE EFFLUENTS

8.1.1. Boric acid

[Ref-1] Analysis of environmental performance in the EPR France project.
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ECEP050315 Revision A1 is the English translation of ECEP050315 Revision A.

[Ref-2] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Annexe B5e. Expected results, excluding hazards of discharges of liquid chemical substances associated with radioactive effluents and waste water from the machine rooms for the EPR nuclear reactor.
ECEF060592 Revision A1. EDF. May 2009. (E)

ECEF060592 Revision A1 is the English translation of ECEF060592 Revision A.

8.1.2. Lithium hydroxide

[Ref-1] Analysis of environmental performance in the EPR France project.
ECEP050315 Revision A1. EDF. March 2012. (E)

ECEP050315 Revision A1 is the English translation of ECEP050315 Revision A.

[Ref-2] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Annexe B5e. Expected results, excluding hazards of discharges of liquid chemical substances associated with radioactive effluents and waste water from the machine rooms for the EPR nuclear reactor.
ECEF060592 Revision A1. EDF. May 2009. (E)

ECEF060592 Revision A1 is the English translation of ECEF060592 Revision A

8.1.3. Zinc acetate

[Ref-1] Zinc Injection claims, arguments and evidences: overall balance for UK-EPR.
ECEF110139 Revision A. EDF. March 2011. (E)

[Ref-2] Zinc Injection Implementation at UK-EPR. ECEF110138 Revision A. EDF. March 2011. (E)

8.1.4. Hydrazine and conditioning amines: morpholine, ethanolamine, ammonia

8.1.4.1. Hydrazine

[Ref-1] Analysis of environmental performance in the EPR France project.
ECEP050315 Revision A1. EDF. March 2012. (E)

ECEP050315 Revision A1 is the English translation of ECEP050315 Revision A.

[Ref-2] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Annexe B5c. ECEF050301 Revision C1. EDF. May 2009. (E)

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[Ref-3] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Annexe B5e. Expected results, excluding hazards of discharges of liquid chemical substances associated with radioactive effluents and waste water from the machine rooms for the EPR nuclear reactor.
ECEF060592 Revision A1. EDF. May 2009. (E)

ECEF060592 Revision A1 is the English translation of ECEF060592 Revision A

8.1.5. Trisodium Phosphate

[Ref-1] Analysis of environmental performance in the EPR France project.
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ECEP050315 Revision A1 is the English translation of ECEP050315 Revision A.

[Ref-2] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Annexe B5e. Expected results, excluding hazards of discharges of liquid chemical substances associated with radioactive effluents and waste water from the machine rooms for the EPR nuclear reactor.
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[Ref-3] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Annexe B5c. ECEF050301Revision C1. EDF. May 2009. (E)

ECEF050301 Revision C1 is the English translation of ECEF050301 Revision C.

8.1.6. Summary of chemical discharges

[Ref-1] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Part B. Chapter III.4 Table B - III.4.1.4.a. - Expected performance excluding contingencies and maximum annual additional discharges for chemicals associated with radioactive effluents. (E)

[Ref-2] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Annexe B5d. EDEAPC050176 Revision D1. EDF. November 2009. (E)

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[Ref-3] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Annexe B5a. EDEAPC050094 Revision D1. EDF. November 2009. (E)

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[Ref-4] Zinc Injection claims, arguments and evidences: overall balance for UK-EPR. ECEF110139 Revision A. EDF. March 2011. (E)

8.2. CHEMICAL DISCHARGES NOT ASSOCIATED WITH RADIOACTIVE EFFLUENT

[Ref-1] DARPE FLA (Authorization request for water intake and liquid and gaseous releases of the Flamanville site) Part B Chapter III.4.2 - Other chemicals discharged into the sea - and associated annexes. (E)