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02	PSCR June 2009 update: - inclusion of references, - clarification of text, - the source terms definitions are corrected, - section 3: paragraphs 3.3 and 3.4 become respectively 3.2.1 and 3.2.2, - the surface activities for Co-58, Ag-110m and Sb-124 are corrected (erratum).	23.06.09
03	Consolidated Step 4 PCSR update: - Minor editorial changes - Clarification of text, - Inclusion of references, - Deletion of text regarding the realistic source term.	27.03.11
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SUB-CHAPTER 12.2 - DEFINITION OF RADIOACTIVE SOURCES IN THE PRIMARY CIRCUIT

During normal plant operation (stabilised operation or shutdown transient conditions), the dose rates arise from activity within the systems and components and/or from surface contamination.

The definition of source terms and specific activities is detailed in Sub-chapter 11.1. For radiation protection purposes, the Biological Protection Design Source Term is used [Ref-1]. This source term is used as a design parameter for EPR buildings, systems and shielding provisions. These values are conservative and come from spectrometric measurements in the N4 units.

Surface deposited activity is detailed in section 2.

Biological protection design values, primary circuit chemistry control, as well as compliance with layout and design principles for complex systems, all play a part in the optimisation of worker radiation protection.

1. SELECTION OF NUCLIDES FOR RADIATION PROTECTION

Because of their radioactive characteristics, some of the radionuclides considered in discharge or accident studies have no significant impact on radiation protection in normal operation.

The radiological impact of radionuclides with a short radioactive half-life such as nitrogen-16 (7.3 seconds) and nitrogen-17 (4.2 seconds) becomes totally negligible after a few minutes simply due to radioactive decay, in shutdown conditions. During Reactor Building access whilst the plant is operational, their contribution is not negligible and has then to be taken into account.

The radiation emitted by the pure beta emitting radionuclides such as tritium, carbon-14 or nickel-63 has sufficiently low energy that it can be stopped by the structures designed to protect against gamma emitting radionuclides.

The primary system inventory of radionuclides which may have an effect on the protection of workers against ionising radiation is given in Sub-chapter 12.2 - Table 1 for stabilised operation, and in Sub-chapter 12.2 - Table 2 for power transients (load reduction for fission products and oxygenation peak for corrosion products).

2. ACTIVATED CORROSION PRODUCT DEPOSITION

During the unit operating life, activated materials transported by the primary fluid can either be deposited on the inner surfaces of the pipework and equipment in contact with this primary fluid or form a mobile solid. This accumulation of contamination is a continuous process that depends mainly on the physical and chemical conditions of the primary system (RCP [RCS]) in the different reactor states (full power and shutdown states).

The distribution of corrosion products in the water also depends on the reactor state.

Specific concentrations and deposited activity of important nuclides in the main loops result from the analysis of measurements made on French power plants [Ref-1]. The deposited values are given for the primary loop in Sub-chapter 12.2 - Table 3.

The deposited values for cobalt-58 and cobalt-60 are responsible for the largest share of dose rates at shutdown.

3. SPECIFIC ACTIVITIES AND ACTIVITY INVENTORY

3.1. PRIMARY CIRCUIT

Radioactive materials in the primary circuit and connected systems arise from:

- fission products released through defects in fuel rod cladding during operation of the unit,
- residual contamination with uranium oxide originating from the scattering of fissile material during preceding campaigns and/or from the manufacturing process,
- corrosion products released by the internal structure of the components and activated by the neutron flux in the core, for instance Co-58 and Co-60,
- primary coolant activation products, for example, H-3 (tritium) or N-16 (nitrogen 16).

For radiation protection, the activity values used to characterise the primary coolant during full power normal operating conditions are those of the Biological Protection Design Source Term. These values have been chosen to cover 100% of values from French N4 plant feedback.

The specific activities for the fission and corrosion products in the primary coolant are given in Sub-chapter 12.2 - Table 1 and Table 2.

The following sections outline the systems and chemistry measures which are being implemented on the EPR to control and optimise the radionuclides inventory in the primary system. Further inventory improvements are obtained from materials design choices as covered in Sub-chapter 12.4.

3.2. PRIMARY CIRCUIT CHEMICAL AND VOLUME CONTROL

Sub-chapter 12.2 - Table 1 gives the activity concentration in the RCV [CVCS] discharge line, with the exception of nitrogen-16 (they are identical to those of the primary system).

The rate of purification in normal operating conditions is 36 te/hour.

For a short period prior to shutdown (72 hours) and during start up, the purification rate may increase up to 72 te/hour to double the purification capacity of additional corrosion products (Co-58, Co-60, Mn-54, Fe-59, Cr-51, etc.) which are released during the forced oxygenation phase (also referred to as ‘crud burst’) of the primary coolant, which occurs prior to reactor cold shutdown. This purification rate increase also aims at retaining high dose pollutants such as Ag-110m, Sb-122 and Sb-124.

The RCV [CVCS] is also used to control and maintain the primary coolant at a constant pH value of 7.2 at 300ºC, which is considered as the optimum value to limit the production and transport of corrosion products. On the EPR, this pH value is obtained by monitoring the conductivity. The RCV [CVCS], and supporting systems, are described in more detail in section 3 of Sub-chapter 9.3.

Primary coolant samples obtained via the nuclear sampling system REN [NSS] are analysed to determine the radioactive composition of the primary coolant and identify any cladding failures. Upon discovery of an increase in predefined fission product inventory levels, the plant is to be shutdown to identify the source of the increase and minimise potential dose rate increases.

3.2.1. Primary Coolant Purification System

The concentration of radionuclides (as ionic or particulate species) in the primary coolant is reduced by running the demineraliser continuously at a purification rate of 10% /hour or 20% /hour.

The primary coolant is subjected to the following successive purification stages:

- fine mechanical filtration using two redundant filters to retain fine insoluble particles (average size 1 µm) with a 99.8% efficiency;
- ion exchange resin treatment, to retain soluble species;
- mechanical resin trap, to retain resin fines which may not be captured by the duty demineraliser strainer.

Primary coolant purification is obtained via separate demineralisers during normal operations and shutdown conditions as further described in Sub-chapter 9.3. In addition, inventory levels and control in these demineralisers is addressed in Chapter 11 with the view of optimising waste production.

3.2.2. Primary Coolant Degasification System

The primary coolant degasification system is mainly used to eliminate hydrogen from the primary circuit before the unit is shut down and to reduce the level of fission gases in the primary coolant during normal operating conditions and particularly before shutdown. The flow rate through the on-line degasification system is set to 72 te/hour, set on the RCV [CVCS] letdown line.

Further detail on the operation of the degasification system can be found in Sub-chapter 9.3.

3.3. PROCESSING AND STORAGE OF PRIMARY EFFLUENTS

The fluid extracted from the primary system to compensate the injection of demineralised water and boric acid for the long-term control of reactivity is transferred to the primary effluent processing and storage system (TEP [CSTS]). In the primary effluent process system, demineralised water and boric acid at 7000 ppm are recovered by evaporation of the borated fluid. If necessary, the boric acid and the distilled water recovered in this way may be re-injected via the REA [RBWMS] into the primary system to increase or reduce the boron concentration as required.

Further detail on waste storage and treatment can be found in section 3 of Sub-chapter 9.3.

3.4. GASEOUS WASTE PROCESSING SYSTEM

The liquid storage tanks, the pressuriser expansion tank, the volume control tank, the gas extractors, the boric acid tanks, the evaporators and several bleed tanks are connected to the gaseous waste processing system TEG [GWPS]. This system is composed of two main functional parts:

- the bleed unit,
- the decay unit.

The gaseous waste processing system (TEG [GWPS]) is mainly filled with nitrogen. The quantity of radioactive isotopes in these units depends on the frequency of degassing, the gas/liquid partition in the tanks linked to the system and the activity released by the decay unit.

Further detail on the operation of the gaseous waste processing system can be found in section 3 of Sub-chapter 11.4.

3.5. SAFETY INJECTION/ REACTOR HEAT REMOVAL AT SHUTDOWN

To shut down the plant under normal operating conditions, the reactor is placed in cold shut down conditions using the reactor heat removal system (RIS-RA [SIS/RHRS]).

When the RIS-RA [SIS/RHRS] is in use, a section of this system conveys primary cooling water with the specific activity of primary coolant. Under other normal operating conditions, the system contains fluid from the In-containment Refuelling Water Storage Tank (IRWST).

3.6. SPENT FUEL POOL WATER TREATMENT AND HEAT REMOVAL

Radioactive impurities in the spent fuel pool water and in the pool heat removal system result from:

- the release of fission products from defective fuel rods,
- the deposit of activated corrosion products on the surface of the stored fuel rods,
- the transport of small quantities of primary coolant via the transfer tube during fuel transfer operations.

The design of the spent fuel pool water treatment and heat removal system is based on the design of this system on existing four loop French PWRs and similar performance is expected. The spent fuel pool water is submitted to the following successive purification steps:

- fine mechanical filtration using two redundant filters;
- ion exchange resin treatment;
- mechanical resin trap.

The resulting activity levels in the PTR [FPC(P)S] must be maintained at as low a level as possible, so that ambient dose rates on the operating floors access routes (Reactor Building and Fuel Building) comply with a green zoning classification.

3.7. MAIN STEAM PIPEWORK

Normally, secondary systems do not contain any radioactivity, as they are completely segregated from the active primary cooling system within the steam generators.

Activity may only enter the secondary system, and hence the main steam system of connected systems, by a leak in a steam generator. During normal operations, leak of 3 litres/hour per Steam Generator has been considered to calculate design basis activity in the main steam system.

SUB-CHAPTER 12.2 - TABLE 1

Specific Concentrations of Radionuclides in the Primary Circuit affecting Radiation Protection: Normal Operation [Ref-1] to [Ref-3]

NUCLIDE	SPECIFIC ACTIVITY (MBq/te)
	Biological protection design value
C-14	1.3E+01
Mn-54	2.2E+02
Co-58	3.9E+02
Fe-59	8.1E+01
Co-60	1.7E+02
Cr -51	6.0E+02
Ni-63	1.5E+01
Ag -110m	2.7E+02
Sb -122	1.1E+02
Sb -124	1.2E+02
Sb -125	9.8E+01
Ar -41	1.0E+03
Kr-85m	5.5E+03
Kr-85	6.2E+02
Kr-87	1.0E+04
Kr-88	1.4E+04
Xe -131m	4.4E+02
Xe -133m	1.7E+03
Xe -133	8.0E+04
Xe -135	1.8E+04
Xe -138	1.4E+04
Sr-89	4.9E+00
Sr-90	3.0E-02
I -131	1.6E+03
I -132	2.8E+03
I -133	4.9E+03
I -134	1.8E+03
I -135	3.3E+03
Cs-134	3.2E+02
Cs-136	3.3E+01
Cs-137	3.2E+02
Cs-138	1.4E+04
H-3	3.7E+04

As tritium has no effect on shielding calculations (pure beta emitter), a single standard value has been defined at 37 GBq/te.

The carbon-14 worst case value derived for the EPR primary coolant is 13 MBq/te. This EPR value is calculated from values measured on the primary coolant in the best French units, balanced by the EPR purification rate compared with that of the existing units during operation.

The radiological impact of radionuclides with a short radioactive life, such as nitrogen-16 (7.3 seconds) and nitrogen-17 (4.2 seconds), becomes totally negligible after a few minutes of decay (during shutdown conditions).

SUB-CHAPTER 12.2 - TABLE 2

Specific Concentrations of Radionuclides in the Primary Circuit Affecting Radiation Protection: Shutdown Transient [Ref-1] to [Ref-3]

NUCLIDE	SPECIFIC ACTIVITY (MBq/te) Biological protection design value
C-14	1.3E+01
Mn-54	3.7E+03
Co-58	2.5E+05
Fe-59	3.7E+04
Co-60	5.9E+03
Cr -51	3.6E+04
Ni-63	3.1E+03
Ag -110m	1.6E+04
Sb -122	1.0E+04
Sb -124	3.7E+03
Sb -125	1.0E+03
Ar -41	1.0E+03
Kr-85m	1.3E+04
Kr-85	1.2E+03
Kr-87	2.3E+04
Kr-88	3.2E+04
Xe -131m	8.3E+02
Xe -133m	3.9E+03
Xe -133	1.5E+05
Xe -135	2.5E+04
Xe -138	4.1E+04
Sr-89	4.9E+02
Sr-90	3.0E+00
I -131	3.7E+04
I -132	3.4E+04
I -133	3.7E+04
I -134	2.4E+04
I -135	2.3E+04
Cs-134	7.7E+03
Cs-136	3.6E+02
Cs-137	6.4E+03
Cs-138	4.1E+04
H-3	3.7E+04

As tritium has no effect on shielding calculations (pure beta emitter), a single standard value has been defined at 37 GBq/te.

The carbon-14 worst case value derived for the EPR primary coolant is 13 MBq/te. This EPR value is calculated from values measured on the primary coolant in the best French units, balanced by the EPR purification rate The radiological impact of radionuclides with a short radioactive life, such as nitrogen-16 (7.3 seconds) and nitrogen-17 (4.2 seconds), becomes totally negligible after a few minutes of decay (during shutdown conditions).

SUB-CHAPTER 12.2 - TABLE 3

Corrosion Products Radioactive Deposits in the Primary Loops (RCP 1, 2, 3, 4) [Ref-1] to [Ref-3]

	Bq/m^2	
Nuclide	**Hot leg/Cold leg**	**Steam generators**
Mn 54	$2.5x10^8 – 4.0x10^8$	$6.5x10^7 – 1.3 x10^8$
Co 58	$3.0x10^9 – 5.2x10^9$	$2.5x10^8 – 2.6 x10^9$
Fe 59	$7.0x10^7 – 2.0x10^8$	$5.0x10^7 – 1.2 x10^8$
Co 60	$5.0x10^8 – 1.25x10^9$	$2.5x10^8 – 5.8 x10^8$
Ag 110 m	$5x10^7$	$2x10^7$
Sb 124	$9x10^7$	$4x10^7$

Note 1:

In order to avoid exceptional pollution events (due to Ag-110m, Sb-122 and Sb-124), recorded in operational feedback from existing units, the design of the primary components in contact with the primary cooling water are designed to avoid metals containing the polluting elements.

With this objective in mind, the main improvements being pursued are:

- a reduction in the use of helicoflex seals in favour of graphite seals,
- increased use of antimony free bearings and stops with submerged rotor,
- use of antimony-free mechanical bearings on concerned pumps.

SUB-CHAPTER 12.2 – 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] Primary Source Term of the EPR Reactor. ENTERP090062 Revision A. EDF. March 2009. (E)

ENTERP090062 Revision A is the English translation of ENTERP070147 Revision A.

2. ACTIVATED CORROSION PRODUCT DEPOSITION

[Ref-1] Primary Source Term of the EPR Reactor. ENTERP090062 Revision A. EDF. March 2009. (E)

ENTERP090062 Revision A is the English translation of ENTERP070147 Revision A.

SUB-CHAPTER 12.2 - TABLES 1 TO 3

[Ref-1] Primary Source Term of the EPR Reactor. ENTERP090062 Revision A. EDF. March 2009. (E)

ENTERP090062 Revision A is the English translation of ENTERP070147 Revision A.

[Ref-2] EPR FA3 Specific Activity Concentrations of Nuclides in Reactor Building Systems. NEEM-F DC 30 Revision F. AREVA. December 2007. (E)

[Ref-3] EPR: activity concentrations in the TEP, REA, TEG, RPE, TEU and TES auxiliary systems. ENTERP070291 Revision A. EDF. November 2007. (E)

ENTERP070291 Revision A is the English translation of ENTERP070070 Revision A.