UK EPR	
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REVISION HISTORY

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01	Integration of technical and co-applicant review comments	28-04-2008
02	PCSR June 2009 Update: – Clarification of text – Inclusion of references – Design evolutions to account for December 2008 design freeze (Primary flow rates and temperatures)	27-06-2009
03	Consolidated Step 4 PCSR update: – Minor editorial changes – Clarification of text – Inclusion and update of references – Update to account for RCCA design change (Table 1 and Figure 1)	26-03-2011
04	Consolidated PCSR update: - References listed under each numbered section or sub-section heading numbered [Ref-1], [Ref-2], [Ref-3], etc	19-07-2011

For information address:

AREVA NP SAS
Tour AREVA
92084 Paris La Défense Cedex
France

EDF
Division Ingénierie Nucléaire
Centre National d'Equipement Nucléaire
165-173, avenue Pierre Brossolette
BP900
92542 Montrouge
France

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SUB-CHAPTER 4.1 – SUMMARY DESCRIPTION

This sub-chapter describes the nuclear, hydraulic and thermal characteristics of the reactor, the assumptions considered at the present stage of the EPR design concerning the mechanical characteristics of the fuel assemblies, and the objectives of the nuclear and thermal-hydraulic design.

1. SUMMARY DESCRIPTION OF THE CORE AND THE FUEL ASSEMBLIES

The reactor core (described in section 2 of Sub-chapter 4.3) contains the nuclear fuel (see section 1 of Sub-chapter 4.2) where the fission reaction, which produces the energy, occurs.

The remainder of the core structure serves either to support the fuel, control the chain reaction, or to channel the coolant.

The reactor core consists of a specified number of fuel rods which are held in bundles by spacer grids and top and bottom fittings. The fuel rods consist of uranium or MOX (uranium plus plutonium) pellets stacked in an M5 cladding tube plugged and seal welded to encapsulate the fuel. The square bundles, known as fuel assemblies, are arranged within the core in a pattern that approximates a cylinder.

Each fuel assembly is formed by a 17 x 17 array, made up of 265 fuel rods and 24 guide thimbles.

The 24 guide thimbles are joined to the grids and the top and bottom nozzles. The guide thimbles are the locations for the rod cluster control assemblies (RCCAs, see section 2 of Sub-chapter 4.2), the neutron source rods, or the in-core instrumentation (see Sub-chapter 7.6). Guide thimbles that do not contain one of these components are fitted with plugs to limit the bypass flow.

The grid assemblies consist of an "egg-crate" arrangement of interlocked straps. The straps contain spring fingers and dimples for fuel rod support, as well as coolant mixing vanes.

The core is radially surrounded by a heavy reflector made of thick steel slabs, whose function is to reflect the neutrons which escape the core back towards the fuel assemblies (see Sub-chapter 4.3).

At the present stage of the EPR design, the example initial core consists of 241 assemblies split up into three regions with different fuel pellet enrichments.

For core reloads, the number and the characteristics of the fresh assemblies depend on reactor operating parameters and the fuel management strategies, i.e., cycle length, type of loading, MOX core, etc. Fuel cycle lengths of 18 and 22 months, an INOUT fuel management regime, uranium or MOX fuel are possible and may be used with the core described herein.

The core is cooled and moderated by light water at a pressure of 15.5 MPa.

2. SUMMARY DESCRIPTION OF THE REACTIVITY CONTROL METHODS

The moderator/coolant contains soluble boron as a neutron poison. The boron concentration in the coolant is varied as required to make relatively slow reactivity changes, including compensation for the effects of fuel burnup. Additional neutron poison (gadolinium), in the form of burnable-poisoned rods, is used to establish the required initial core reactivity and power distribution.

The core reactivity and the core power distribution are also controlled by movable Rod Cluster Control Assemblies (RCCAs), which are neutron absorber rods that enable rapid changes in reactivity to be made.

Each RCCA consists of a group of individual absorber rods fastened at the top end to a common hub or spider assembly. The RCCAs are split into several groups. The Control Rod Drive Mechanisms (RGL [CRDM]) move the RCCAs and enable them to be dropped, to remain as they are, or to be withdrawn. The RGL [CRDM]s are electromechanical devices fixed to the reactor vessel cap. They control the RCCA position and ensure the reactor trips by interrupting the RGL [CRDM] electrical supplies, which causes the RCCAs to drop by gravity into the fuel assemblies.

3. OBJECTIVES OF THE NUCLEAR AND THERMAL-HYDRAULIC DESIGN ANALYSES

The nuclear design analyses and evaluations establish physical locations for the control rods and burnable poison rods, and physical parameters such as fuel enrichments and boron concentration in the coolant. The nuclear design evaluation established that the reactor core has inherent characteristics which, together with the reactor control and protection systems, provide adequate reactivity control even if the highest reactivity worth RCCA is stuck in the fully withdrawn position.

The design also provides for inherent stability against radial and axial power oscillations, and for control of axial power oscillation induced by control rod movements.

The thermal-hydraulic design analyses and evaluations establish coolant flow parameters which ensure adequate heat transfer between the fuel cladding and the reactor coolant. The thermal design takes into account local variations in dimensions, power generation, flow distribution, and mixing. The mixing vanes incorporated in the fuel assembly spacer grid design induce additional flow mixing between the various flow channels within a fuel assembly, as well as between adjacent assemblies. Instrumentation is provided within and outside the core to monitor the nuclear, thermal-hydraulic, and mechanical performance of the reactor, and to provide inputs to automatic control functions.

4. COMPILATION OF THE REACTOR DESIGN PARAMETERS

The principal reactor nuclear, thermal-hydraulic and mechanical design parameters are presented in Sub-chapter 4.1 - Table 1.

5. DESIGN METHODS AND TOOLS

The analytical techniques used in the core design are listed in Sub-chapter 4.1 - Table 2.

6. COMPUTER CODES

The description, nature, and objective of the computer codes used in the core design are presented in Appendix 4 of this PCSR.

SUB-CHAPTER 4.1 - TABLE 1 (1/7)

Reactor Design Parameters [Ref-1]
(The dimensions given are at cold conditions (20˚C))

A - Thermal and hydraulic design parameters:	
1 - Reactor core heat output (100%) (MWth)	4500
2 - Number of loops	4
3 - Heat generated in fuel (%)	97.4
4 - Nominal system pressure (bar)	155
5 - DNB (Departure from Nucleate Boiling) predictor	FC-CHF[1] Correlation (See Sub-chapter 4.4)
6 - Minimum DNBR (Departure from Nucleate Boiling Ratio) under nominal operating conditions ($F\Delta H$ = 1.61 - cos 1.45) [2]	2.6
7 - Minimum initial DNBR for the Basic Design transient analyses	(see Chapter 14)
B - Coolant flow:	
8 - Thermal design flow rate/loop (m^3/h)	27185
9 - Core bypass flow rate (%)	5.50
10 - Core flow area for heat transfer (m^2)	5.9
11 - Average velocity along fuel rods (m/s)	5
12 - Core average mass velocity ($g/cm^2.s$)	356

[1] Critical Heat Flux
[2] See Sub-chapter 4.4

SUB-CHAPTER 4.1 - TABLE 1 (2/7)

Reactor Design Parameters [Ref-1]
(The dimensions given are at cold conditions (20˚C))

C - Coolant temperature (preliminary):	
13 - Nominal inlet (°C)	295.6
14 - Average rise in vessel (°C)	34.2
15 - Average rise in core (°C)	36.0
16 - Average in core (°C)	313.6
17 - Average in vessel (°C)	312.7
D - Heat transfer:	
18 - Heat transfer surface area (m^2)	8005
19 - Average core heat flux (W/cm^2)	54.7
20 - Maximum core heat flux (nominal operation) (W/cm^2)	157.3
21 - Average linear power density (based on cold dimensions) (W/cm)	163.4
22 - Peak linear power for normal operating conditions (W/cm)	470
23 - Peak linear power protection set point (W/cm)	590
24 - Peak linear power for prevention of centreline melt (W/cm)	> 590
25 - Power density in hot conditions (kW/core litre)	94.6

SUB-CHAPTER 4.1 - TABLE 1 (3/7)

Reactor Design Parameters
(The dimensions given are at cold conditions (20˚C))

E - Vessel and core pressure losses:	
26 - Reactor vessel (bar):	3.44
27 - Core (bar):	1.88
F - Fuel assemblies (preliminary)	
28 - Rod array	17 x 17
29 - Number of fuel assemblies	241
30 - Rods per assembly	265
31 - Fuel assembly pitch (cm)	21.504
32 - Fuel assembly length without hold-down spring (cm)	480
33 - Lattice rod pitch (cm)	1.26
34 - Overall transverse dimensions (cm)	21.4 x 21.4
35 - Fuel weight per assembly (kg)	598 UO_2 527.5 U
36 - Number of grids per assembly	10
37 - Composition of grids	Zircaloy & Inconel
38 - Number of guide thimbles per assembly	24
39 - Number of instrumentation thimbles per assembly	0
40 - Diameter of guide thimbles, upper part (mm)	11.45 inside 12.45 outside

SUB-CHAPTER 4.1 - TABLE 1 (4/7)

Reactor Design Parameters
(The dimensions given are at cold conditions (20˚C))

G - <u>Fuel rods</u> <u>(preliminary)</u>	
41 - Number	63865
42 - Outside diameter (mm)	9.50
43 - Diametric gap (mm)	0.17
44 - Cladding thickness (mm)	0.57
45 - Cladding material	M5
H - <u>Fuel pellet</u> <u>(preliminary)</u>	
46 - Material	UO_2 or MOX
47 - UO_2 density (% of the theoretical density)	95
48 - UO_2 + PuO_2 density (% of the theoretical density)	94.5
49 - Diameter (mm)	8.19

SUB-CHAPTER 4.1 - TABLE 1 (5/7)

Reactor Design Parameters [Ref-2]
(The dimensions given are at cold conditions (20˚C))

I - Rod Cluster Control Assemblies (preliminary) See also Sub-chapter 4.1 - Figure 1	
50 - Absorber	
AIC composition (%wt)	
Ag	80
In	15
Cd	5
AIC density (g/cm^3)	10.17
1) AIC part (upper part)	
Absorber outer diameter (mm)	8.66
Length (mm)	2400
2) AIC part (lower part)	
Absorber outer diameter (mm)	8.53
Length (mm)	500
3) B4C part (upper part)	
Composition: natural boron (19.9% atomic wt. of B-10)	
Density (g/cm^3)	1.79
Absorber diameter (mm)	8.47
Length (mm)	1340
51 - Cladding	
Outer diameter (mm)	9.68
Inner diameter (mm)	8.74
Thickness (mm)	0.47
Material	Stainless steel
52 - Number of clusters, full length	89
53 - Number of absorber rods per cluster	24

SUB-CHAPTER 4.1 - TABLE 1 (6/7)

Reactor Design Parameters
(The dimensions given are at cold conditions (20˚C))

J - Active core	
54 - Equivalent diameter (mm)	3767
55 - Core average active fuel height (mm)	4200
56 - Height-to-diameter ratio	1.115
57 - Total cross-section area (cm^2)	111440
K - Heavy, radial reflector (preliminary)	
58 - Thickness (mm)	Between 77 and 297 (average 194)
59 - Composition (% volume)	95.6% steel, 4.4% water

SUB-CHAPTER 4.1 - TABLE 1 (7/7)

Reactor Design Parameters
(The dimensions given are at cold conditions (20˚C))

L - Fuel enrichment (preliminary):	
For UO_2 fuel assemblies (% wt):	
60 - Region 1 of cycle 1	2.1 %
61 - Region 2 of cycle 1	3.2 %
62 - Region 3 of cycle 1	4.2 %
63 - Fresh assemblies for UO_2 - INOUT - 18 months	5.0 %
64 - Fresh assemblies for UO_2 - INOUT - 22 months	5.0 %
For MOX fuel assemblies (% wt)[3]:	
65 - Maximum fissile Pu enrichment for zone 1	7.44 %
66 - Middle fissile Pu enrichment for zone 2	6.44 %
67 - Minimum fissile Pu enrichment for zone 3	3.44 %
68 - Average fissile Pu enrichment	7.0 %
69 - Assumption for UO_2 enrichment in MOX fuel (% U-235 wt)	0.2 %
M - Pu isotopic content of MOX fuel assemblies produced by UO_2 fuel at a burnup of 60 GWD/t recovery (% wt):	
70 - Pu 238	4.0
71 - Pu 239	50.0
72 - Pu 240	23.0
73 - Pu 241	12.0
74 - Pu 242	9.5
75 - Am 241	1.5

[3] The fissile Pu enrichment is defined as $e = \frac{Pu239 + Pu241}{(U + Pu + Am)}$

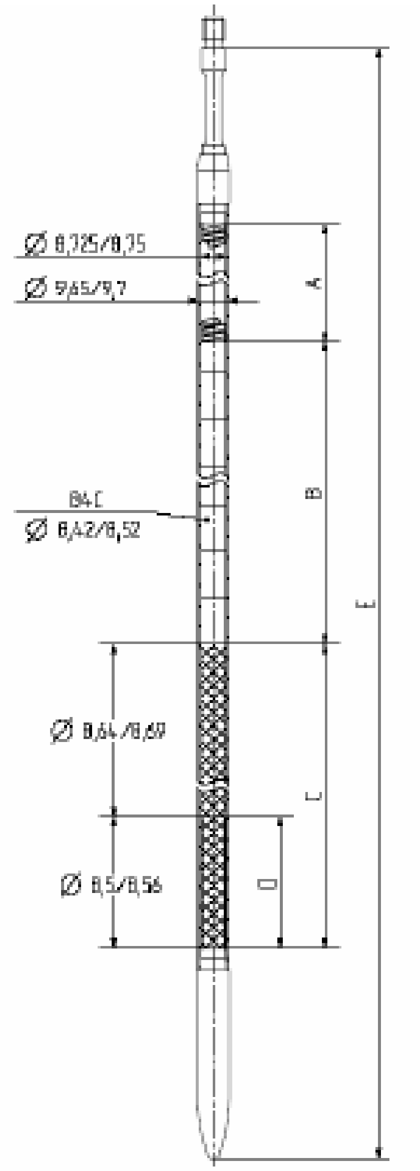
SUB-CHAPTER 4.1 - TABLE 2

Analytical Techniques in Core Design

ANALYSIS	TECHNIQUE	COMPUTER CODE
1 - Nuclear design		
• Cross sections and group constants	Macroscopic data	APOLLO 2
• Power distributions, fuel burnup critical boron concentration, xenon distributions, reactivity coefficients, rod worths.	3-D, 2-group, diffusion evolution theory	SMART
2 - Thermal-Hydraulic design	Sub-channel analysis of local fluid conditions (analysed for the core, the assembly, and the hot channel)	FLICA III-F

SUB-CHAPTER 4.1 - FIGURE 1

Absorber Rod
(The dimensions given are at cold conditions (20˚C))



Dimension A	mm	162.9
Dimension B	mm	1340
Dimension C	mm	2900
Dimension D	mm	500
Dimension E	mm	4520.5

SUB-CHAPTER 4.1 – REFERENCES

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

SUB-CHAPTER 4.1 - TABLE 1

[Ref-1] S Laurent. EPR FA3 – NSSS Operating parameters. NFPSC DC 1042 Revision C. AREVA. December 2006. (E)

[Ref-2] EPR HARMONI® RCCA - Description, Functional Requirements and Materials Properties. FF DC 05182 Revision B. AREVA. July 2009. (E)