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General VHTR Plant Design Data

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General VHTR Plant Design Data

Abstract

This report gathers the reference VHTR plant design data to be used in the framework of the RAPHAEL work programme.
This is the first version which only gives information provided by AREVA NP and related to the ANTARES design as a prismatic type reactor.

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SUMMARY

This report gathers the reference VHTR plant design data to be used in the framework of the RAPHAEL workprogramme

KEY WORDS

VHTR, RAPHAEL

ABBREVIATIONS

VHTR	Very High Temperature Reactor
RAPHAEL	Reactor Application for Process heat Hydrogen And ELectricity
ANTARES	Areva New Technology for Adavnced Reactor for Energy Supply
NGNP	Next Generation Nuclear Plant
PBMR	Pebble Bed Modular Reactor
LEU	Low Enriched Uranium
EFPD	Equivalent Full Power Day
HM	Heavy Metal
IHX	Intermediate Heat eXchanger
FE	Fuel Element

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1. INTRODUCTION

This report gathers the reference VHTR plant design data to be used in the framework of the RAPHAEL workprogramme.

The present release only gives informations provided by AREVA NP and related to the ANTARES design as a prismatic type reactor. Similar informations for a pebble bed type reactor are still expected directly from PBMR Co, or undirectly from NSL, but are currently unavailable.

2. VHTR PLANT DATA FROM THE ANTARES DESIGN

2.1. General

The reactor applies the block-type (prismatic) core design, in which the coated particle fuel, a common feature of all HTRs, is contained within prismatic graphite blocks that are arranged to form an annular core geometry. The 102 column, 10 block high active core utilizes a once-through low enriched uranium (LEU) fuel cycle and operates in the epithermal neutron spectrum. The core is sized to produce 600MW of thermal power, with a target core outlet temperature of 950°C, primarily for advanced heat applications including hydrogen production. Helium is used as the primary heat transport medium.

The thermal power produced in the core is transferred to a secondary loop via an intermediate heat exchanger (IHX), where it is utilized to drive the application of interest.

The reactor and IHX are contained within separate steel pressure vessels. The reactor and IHX vessels are linked by a cross-vessel which contains an internally insulated hot duct for routing helium from and to the reactor. Normal coolant circulation is provided by a helium circulator, located at the top of the IHX (although this arrangement is not frozen).

The reactor and the IHX vessels are housed in separate concrete enclosures that are fully embedded below ground in a silo-type structure. Above ground structures are provided to house the fuel handling system, helium processing, reactor services, reactor control systems and other plant auxiliary systems.

The AREVA NP VHTR nuclear heat source incorporates several important innovative departures from the other HTR designs. The most significant difference is the decision to employ an indirect cycle design. The indirect cycle offers several advantages. First and foremost, it allows a common heat source to be used for several types of downstream applications (e.g. process heat, electricity) and minimizes the complexity and risk associated with the nuclear part of the cycle. This is illustrated in Figure 1. The indirect cycle design also eliminates the potential for contamination of the downstream process equipment by radionuclides carried within the primary helium coolant. In addition, separating the nuclear heat generation systems, structures and components from the industrial application processes simplifies reactor licensing, startup, operating procedures, and maintenance.

The second major advantage offered by the indirect cycle design is the freedom to select a secondary coolant. The AREVA NP design for electricity generation utilizes a mixture of nitrogen and helium with properties similar to air as the secondary heat transport fluid. Helium is the reference secondary fluid for coupling the hydrogen production application; however, with the indirect cycle design, other heat transport media can be considered.

The final key feature is the selection of a relatively reduced reactor inlet temperature at 400°C. This selection leads to several advantages. The temperatures seen by the reactor vessel are lower. With reduced inlet temperature, the flow rate and circulator power are lower and a reduction in the primary pressure becomes practical as a trade off. The lower system pressure translates to a reduced vessel wall thickness, which has significant fabrication and cost advantages. In addition, the thermal energy stored in the core is reduced, thus enhancing passive decay heat removal during certain transients.

2.2. Core data

The annular active core arrangement is built of 1020 blocks stacked up in 102 columns of 10 blocks each, roughly making up 3 rings of 30, 36 and 36 columns, respectively. Among them, 30 columns have a dedicated channel for the introduction of an absorber element, 12 for start-up control rod and 18 for reserve shutdown control element. The other 72 columns do not comprise such a channel. The core layout is shown in Figure 2.

The top and bottom reflectors are arranged above and below the FEs arrangement, respectively. Replaceable reflector columns are also arranged in the inner and outer zones of the core annulus, with 61 and 102 columns respectively. Among the 102 columns of the outer reflector arrangement, 36 have a dedicated channel for the introduction of an absorber element (operating control rod).

The hexagonal pitch is 362 mm at room temperature (20°C) including a radial gap between stacks of 2 mm.

The main core dimensions are the following:

– outer equivalent diameter of annular core zone	:	4.84	m
– inner equivalent diameter of annular core zone	:	2.96	m
– height of fuel element stack	:	8.00	m
– height including top and bottom replaceable reflectors	:	10.10	m
– diameter of outer permanent reflector	:	6.84	m

The main core functional characteristics are:

– Uranium enrichment	:	14 % mass	
– Fuel management	:	2 batches	
– Equilibrium cycle length	:	450 EFPD	
– Core average power density	:	6.5	W/cm^3
– Uranium inventory in the core	:	4570	kg (metal)
– Average fuel burn-up at discharge	:	120	GWd/tHM
– Core inlet temperature	:	400 °C	
– Core outlet temperature	:	950 °C	
– Helium flowrate	:	210 kg/s	

2.2.1. Fuel element

There are two types of fuel elements:

– Standard fuel elements comprising fuel and helium channels only.

– Fuel elements with a dedicated channel for absorber element motion.

Main technical data of fuel elements are given in Table 2.

AL: N ECCN: N

Fuel compact

The fuel compact is a cylindrical stick of 50 mm height and 12.5 mm outer diameter consisting of fuel particles mixed in a pressed graphite matrix. Artificial graphite based on non-calcined petroleum cokes with low content of impurities is used as a filler for matrix composition. Each compact contains about 2500 fuel coated particles.

Fuel compacts are stacked in channels of 12.7 mm diameter drilled in the graphite block.

A nominal radial gap of 0.1 mm between the fuel compact and the fuel compact channel in the graphite block provides an opportunity to assemble the FE and minimizes stresses appearance in graphite structure during operation.

Fuel particle

The dimensions of the reference coated particle are given hereafter:

- UO_2 kernel diameter : 0.500 mm
- Buffer thickness : 0.095 mm
- Inner PyC thickness : 0.040 mm
- SiC thickness : 0.035 mm
- Outer PyC thickness : 0.040 mm
- Outer diameter of fuel particle : 0.920 mm

2.2.1.1. Standard fuel block

The standard fuel block has 216 channels of 12.7 mm diameter for fuel compacts and 108 channels of 16 mm diameter for coolant flow, Figure 3. The six coolant channels surrounding the handling hole are smaller. Their diameter is 12.7 mm.

In each fuel channel there are 15 fuel compacts so as there are 3240 fuel compacts per fuel block.

Fuel channels are closed by a graphite plug on the top side of the fuel block.

Fuel block has channels for fuel compact and helium coolant.

2.2.1.2. Fuel block with channel for absorber element

This fuel block has one channel of 130 mm diameter for start-up or reserve shutdown absorber rod passage, 174 channels of 12.7 mm diameter for fuel compacts and 89 channels of 16 mm diameter for coolant flow, Figure 3.

In each fuel channel there are 15 fuel compacts so as there are 2610 fuel compacts per fuel block.

Fuel channels are closed by a graphite plug on the top side of the fuel block.

2.3. IHX data

The IHX comprises multiple modules of a compact heat exchanger design that is optimized for high effectiveness and minimum approach temperatures, while providing for high reliability and maintainability. IHX technology options include either tubular or plate configurations.

Main operating conditions of the two IHX options are given in Table 1.

FIGURE 1: ANTARES INDIRECT CYCLE ARRANGEMENT

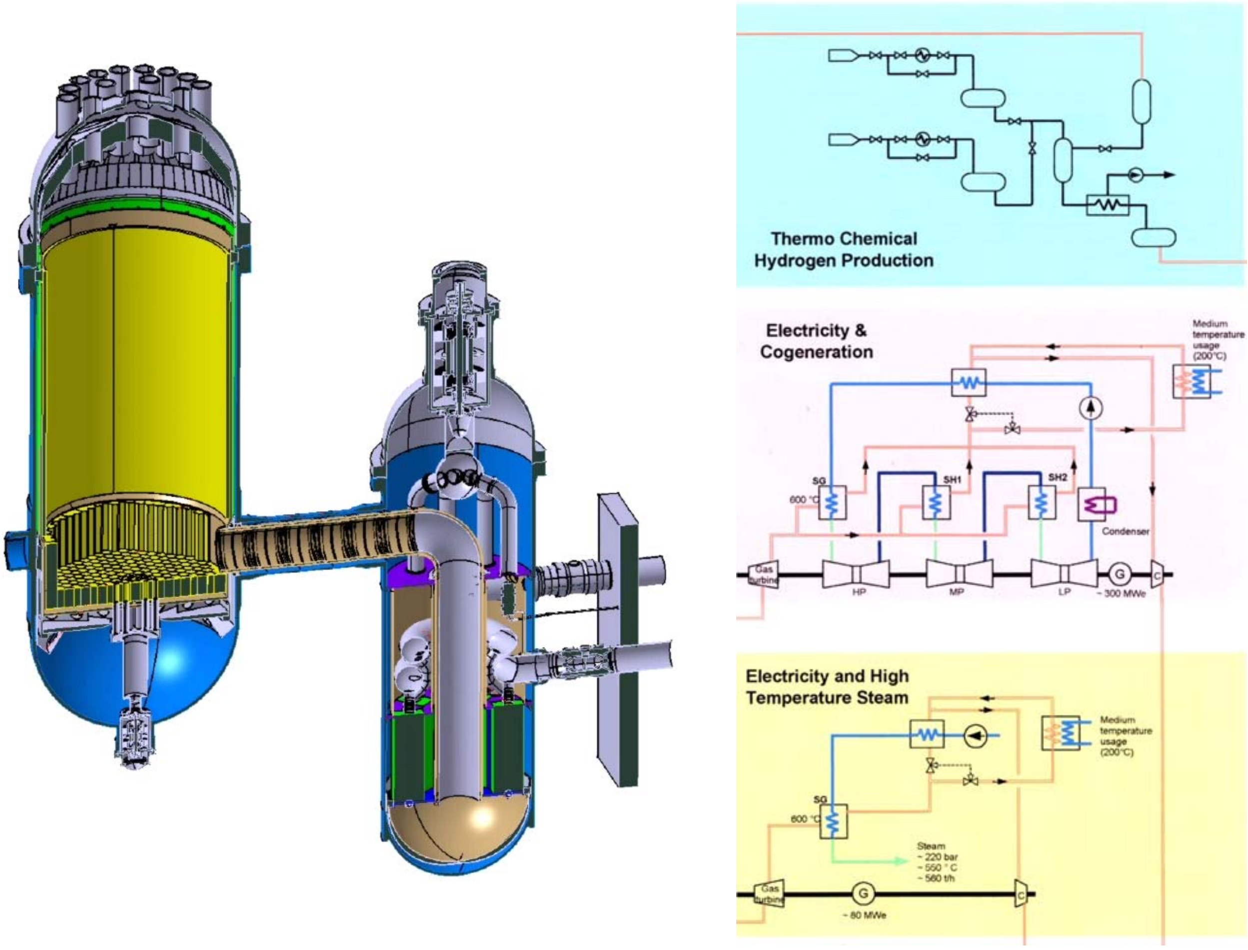

FIGURE 2: ANTARES CORE LAYOUT

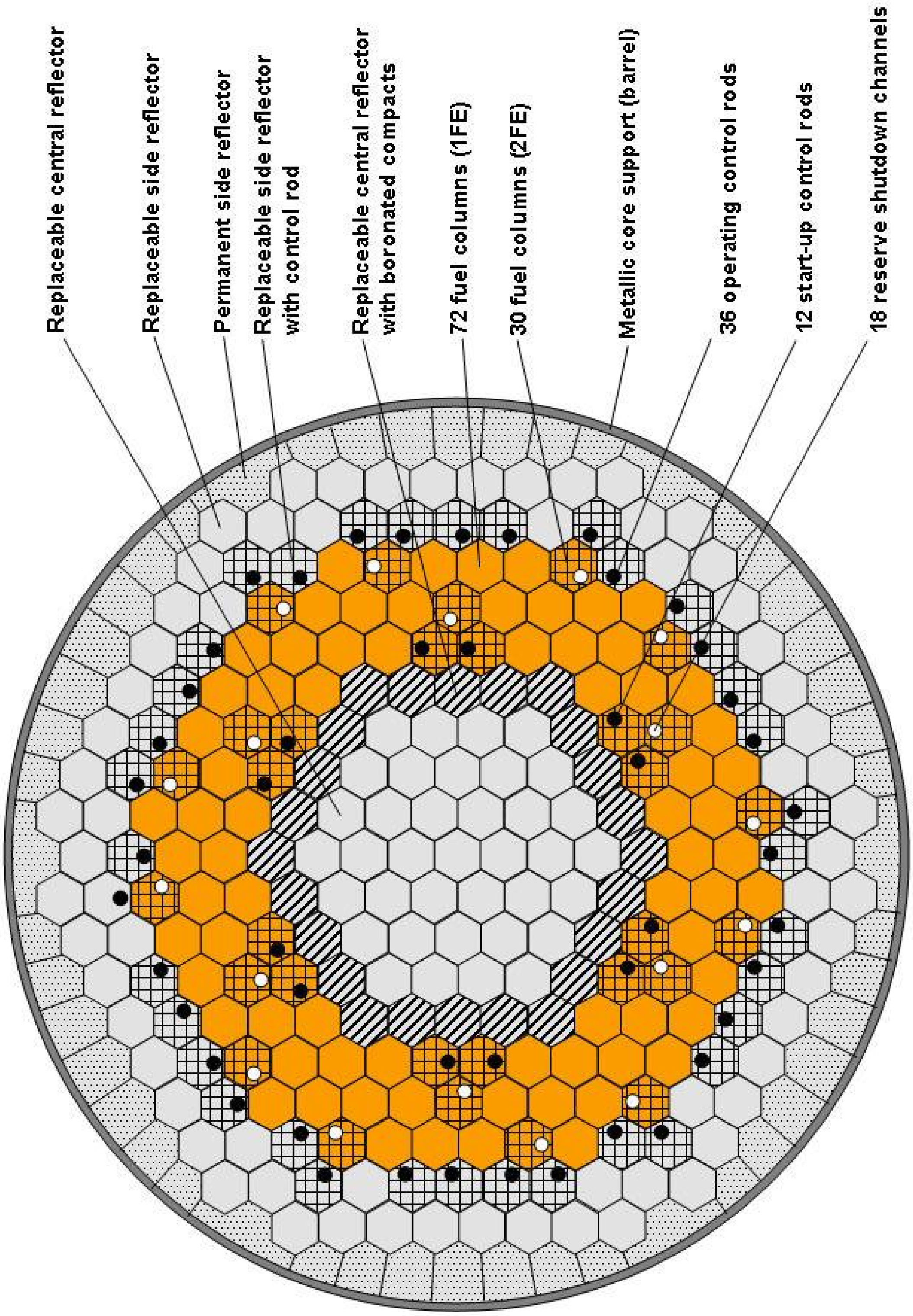

FIGURE 3: ANTARES FUEL BLOCK

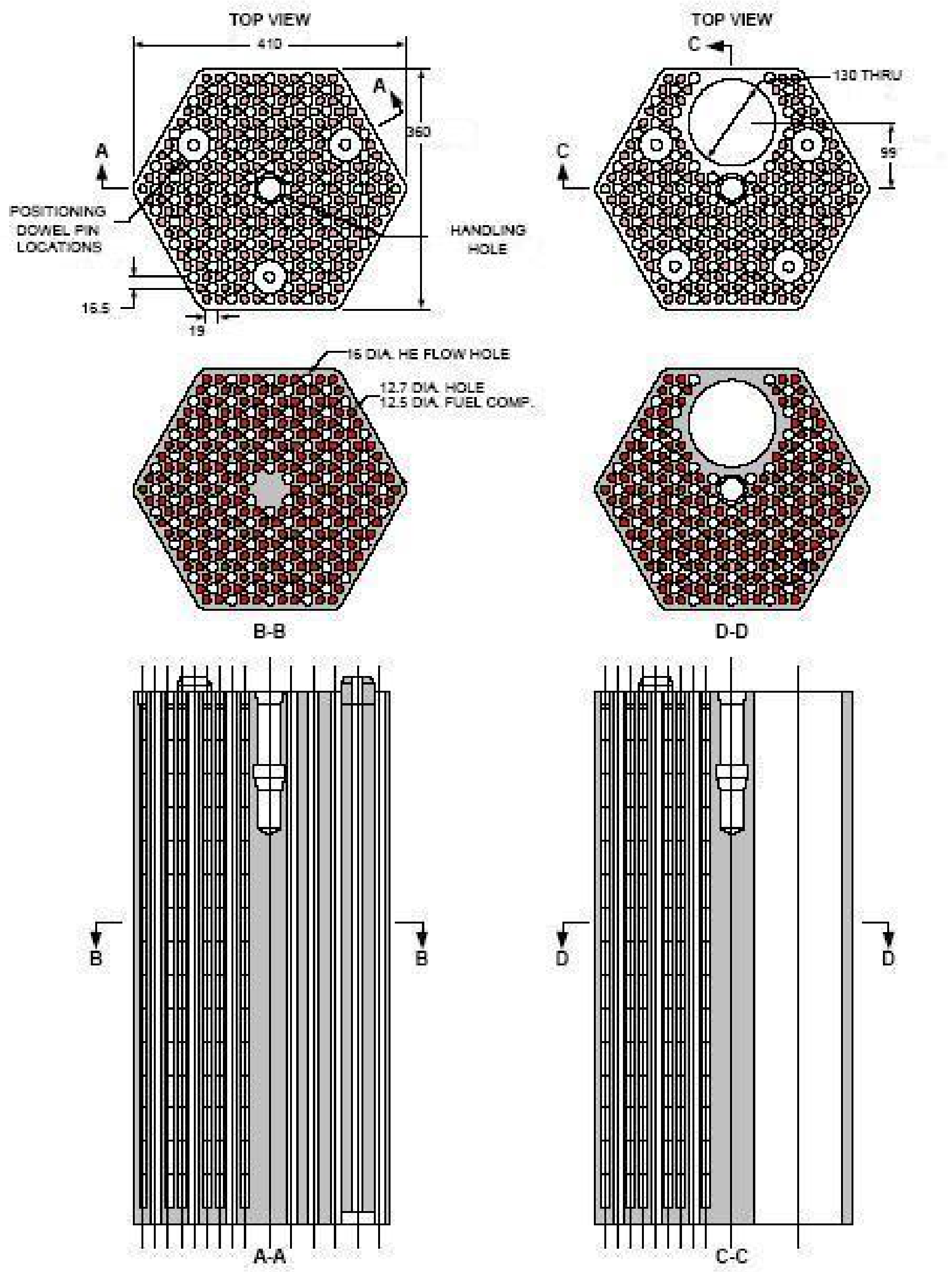

TABLE 1: MAIN VHTR DATA - AREVA PROPOSAL

Primary circuit operating data for the coupling with a H_2 plant based on a thermochemical process

	Opt 1	Opt 2
Reactor power	600 MWt	600 MWt
Core inlet temperature	400°C	400°C
Core outlet temperature	950°C	950°C
Primary pressure	5.0 MPa	5.5 MPa
Number of primary circulators	2	1
IHX type	Tube	Plate
Reactor vessel material	9 Cr	9 Cr
Secondary fluid	He	He

Opt 1 tube IHX	Primary Helium	Secondary Helium
IHX outlet temperature	390°C	900°C
IHX inlet temperature	950°C	340°C
IHX inlet Primary pressure	5 MPa	4.5 MPa
Flow rate (kg/s)	210	210
IHX Max pressure loss	2 %	2 %
IHX Power	610 MWt	
IHX Effectiveness	90 %	
Primary circulators (2) pressure head	0.15 - 0.2 MPa	
Primary circulators (2) power	Around 10 MWt	
Primary circulators (2) inlet T	390 °C	
Primary circulators (2) outlet T	400°C	

Opt 2 plate IHX	Primary Helium	Secondary Helium
IHX outlet temperature	390°C	900°C
IHX inlet temperature	950°C	340°C
IHX inlet Primary pressure	5.5 MPa	5.0 MPa
Flow rate (kg/s)	210	210
IHX Max pressure loss	2 % (1.5 % for IHX core)	2 % (1.5 % for IHX core)
IHX Power	610 MWt	
IHX Effectiveness	90 %	
Primary circulator pressure head	0.15 - 0.2 MPa	
Primary circulator power	Around 10 MWt	
Primary circulator inlet T	390 °C	
Primary circulator outlet T	400°C	

TABLE 2: ANTARES FUEL BLOCK DATA

Parameter	Value
Flat to flat size (mm)	360
Height (mm)	800
Active length (mm)	750
Control rod and RSS hole diameter (mm)	130
Number of standard fuel element in the core	720
Number of control fuel element in the core	300
Number of fuel channels standard fuel element (1F type) control fuel element (2F type)	 216 174
Number of coolant channels standard fuel element (1F type) control fuel element (2F type)	 108 89
Number of compacts in one hole of fuel element	15
Number of fuel compacts in the core	3 115 800