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NGNP Conceptual Design – Point Design

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Safety Related? ☐ YES ☒ NO

Does this document contain assumptions requiring verification? ☐ YES ☒ NO

Signature Block

Name and Title/Discipline	Signature	P/LP, R/LR, A/A-CRF	Date	Pages/Sections Prepared/Reviewed/ Approved or Comments
James R. Geschwindt/Principal Engineer/HTR Nuclear Island	James R. Geschwindt	P	4/27/09	All
John Mayer/Advisory Engineer/HTR Nuclear Island	John Mayer	R	4/27/09	All
Lew Lommers/HTR Project Engineering Manager	L. Lommers	A	4/27/09	All

Note: P/LP designates Preparer (P), Lead Preparer (LP)
R/LR designates Reviewer (R), Lead Reviewer (LR)
A/A-CRF designates Approver (A), Approver of Customer Requested Format A-CRF

Record of Revision

Revision No.	Date	Pages/Sections/ Paragraphs Changed	Brief Description / Change Authorization
000	3/19/2009	All	Initial issue.
001	4/23/2009	All	Editorial and formatting changes made throughout document.
		Pg. 8	Changed affect(s) to effect(s). Changed text from “a balance was made” to “a balance was considered”.
		Table 3-1 and Table 4-1.	Clarified location and description titles and made them consistent with those of the Plant Design Requirements Document (PDRD) [1].
		Pg. 10	For clarity, a description was added for main circulator efficiency. Also added were definitions of active core flow, core bypass flow, and reactor flow.
		Figures 4-1, 4-2, and 4-3	Updated flow rate and circulator titles for clarity and to be consistent with PDRD [1].
		Table 4-2	Added Core bypass flow rate, reactor flow rate, and adjusted core flow rate title for clarification. Added SG outlet steam pressure to table. Made description titles consistent with the Plant Design Requirements Document [1] and made them self-consistent regarding capitalization.
		Section 6.0	Added Plant Design Requirements Document reference (reference [1]). Updated revision numbers for references.

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1.0 INTRODUCTION

1.1 Background and Purpose

The NGNP is a modular high temperature gas-cooled reactor. The reference concept of the NGNP design, described in the design baseline document [2], is a conventional steam cycle for process heat and electricity cogeneration. The purpose of this document is to establish heat balance parameters for full power operation based on this reference concept.

1.2 Organization of Document

Section 2.0 describes the approach to establishing the point heat balance. Allocation and design margins are detailed in section 3.0. Section 4.0 describes the point heat balance and key plant parameters developed from the heat balance. Sections 5.0 and 6.0 contain the conclusions and references, respectively.

1.3 Acronyms

Table 1-1 shows acronyms used throughout this document.

Table 1-1: Abbreviations and Acronyms

Acronym	Description
HTS	Heat Transport System
NGNP	Next Generation Nuclear Plant
NHS	Nuclear Heat Supply System
PCS	Power Conversion System
RCCS	Reactor Cavity Cooling System
SCS	Shutdown Cooling System
SG	Steam Generator

2.0 APPROACH

Key plant parameters, along with plant allocations defined in this document, were used to establish a plant point heat balance, described in section 4.0. The heat balance in this document covers a steady-state point at 100% reactor power for each of three modes of plant cogeneration operation: all electric production, all process heat production, and an even split of power between these uses. Since the secondary steam side of the plant is not well defined, the heat balance details focus on the primary helium loop.

Since the reference design is in its initial stages, the results of this document should be considered preliminary and this document will be periodically updated. As such, all parameter values shown in brackets [] are considered preliminary and are subject to change as the design evolves. As the design matures, and the parameters solidify, the brackets will be removed from these values.

3.0 ALLOCATIONS AND DESIGN MARGINS

This document defines initial pressure drop and heat transfer allocations, and corresponding design margins, for key plant parameters for the NGNP reference plant configuration. These parameters include primary helium circuit pressure losses (Table 3-1), component heat losses (Table 3-2), and hot/cold gas duct regenerative heating (Table 3-3). SG heat transfer margins will eventually be included in this table as this document is revised, but for now this value is [TBD].

Before allocating system pressure losses, a primary side helium pressure (circulator outlet pressure) needs to be selected. The effect of system pressure was considered on primary loop pressure loss, circulator power and reactor vessel stresses. A balance was considered among circulator power requirements, circulator design maturity, and reactor vessel structural limits and costs. This trade-off resulted in the preliminary selection of a primary system pressure of 6 MPa. This value is preliminary since a detailed trade study on the effects of primary helium pressure will be performed in the future. This preliminary pressure value of 6 MPa will be revised accordingly.

Based on the 6 MPa primary helium pressure, preliminary allocations and margins can be made on primary system pressure drop which is illustrated in Table 3-1.

Table 3-1: Primary Helium Side Pressure Drop Allocations and Margins

Location	Allocation Value (kPa)
Reactor Internals	[5]
Reactor Core (includes top and bottom reflector blocks)	[66]
HTS Internals	[7]
SG Bundle	[30]
Design Margin	[14]
Total (required Main Helium Circulator pressure rise)	**[122]**
Required Main Helium Circulator Power Input	**[3.6] MWth x 2**
Required Main Helium Circulator Power	**[4] MWe x 2**

Heat loss allocations and margins are shown below in Table 3-2.

Table 3-2: Heat Loss Allocations and Margins

Location	Allocation Value (MWth)
Reactor (to RCCS)	[1.4]
SCS (primary helium flow leakage through shutdown heat exchanger)	[0.3]
SG	[0.2] ([0.1] x 2 SGs)
Design Margin	[0.4]
Total	**[2.3]**

Table 3-3 shows the initial allocation and margin for the regenerative heating in the cold and hot gas ducts. This heating occurs due to the concentric design of these ducts. The thermal conduction path occurs through the insulation in these concentric ducts.

Table 3-3: Hot/Cold Gas Duct Regenerative Heating Allocation and Margin

Location	Allocation Value (MWth)
Hot/cold gas duct	[0.16] ([0.08] x 2)
Design Margin	[0.08]
Total	[0.24]

4.0 HEAT BALANCE

4.1 100% Reactor Power Heat Balance for a Generic Secondary Side Configuration.

Plant allocations defined in this document (Table 3-1, Table 3-2, and Table 3-3) along with key plant parameters defined in Table 4-1, were used to establish plant point heat balances. Three heat balances have been established in this document, one for each of three cogeneration modes of operation at rated power: 100% electricity production, 50%/50% electricity/ process heat production, and 100% process heat production. Since the secondary steam side of the plant is not well defined, each heat balance focuses on the primary helium loop and shows a generic secondary steam side with PCS and process heat. Figure 4-1, Figure 4-2, and Figure 4-3 show these three heat balances and key plant parameters, which reflect allocations <u>including design margins</u>. Note that the 90% circulator efficiency shown in the heat balances is an overall efficiency that includes electrical and thermodynamic losses. Table 4-2 summarizes key plant parameters. Note the breakdown of reactor flow rate into active core flow rate and core bypass flow rate. The definitions of these flow rates are as follows: active core flow rate is the helium flow that goes through the core cooling passages. Core bypass flow is any helium flow through the reactor vessel, except for SCS leakage flow, that does not flow through the core cooling passages. For the heat balances the only flow cooling the core is the active core flow.

Table 4-1: Key Plant Parameters used for the Point Design Heat Balances

Description	Baseline Value
Nuclear Island	
Power level	[625] MWth
Reactor Core	
Core inlet temperature	[325]°C
Core outlet temperature	[750]°C
Main Heat Transport System	
Primary Pressure	[6.0] MPa
Steam Generator Unit	
Steam-Water Side Inlet Temperature	[281.5]°C
Steam-Water Side Outlet Temperature	[566]°C
Steam Outlet Pressure	[16.7] MPa
Pressure Drop (tube side) Steam/Water side	[7.6] MPa

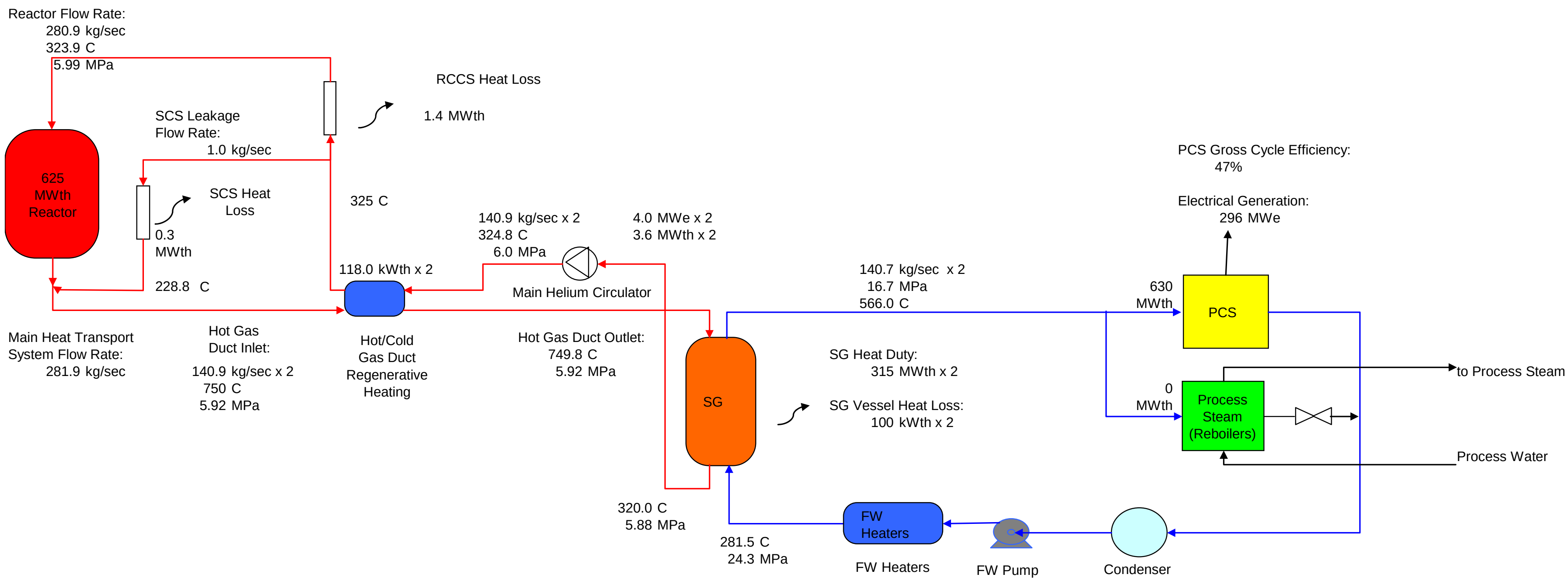

Figure 4-1: Heat Balance at Rated Power for 100% Electricity Production

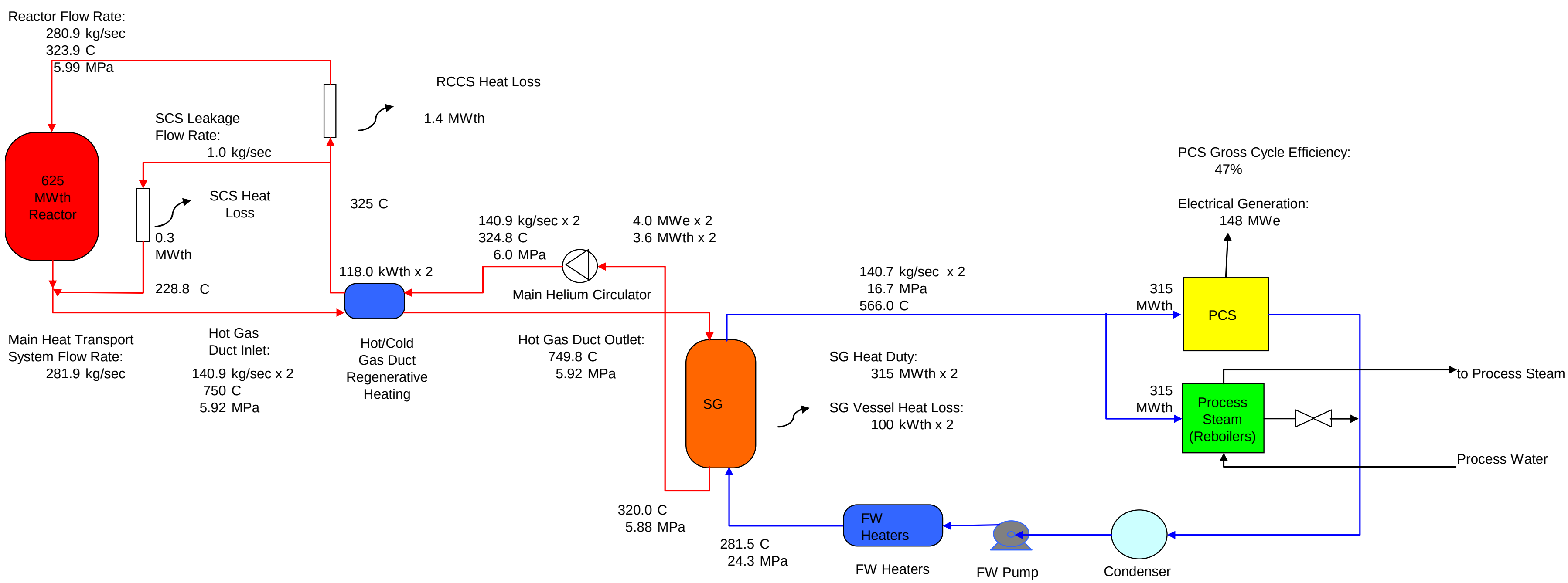

Figure 4-2: Heat Balance at Rated Power for 50%/50% Electricity Production and Process Heat Production

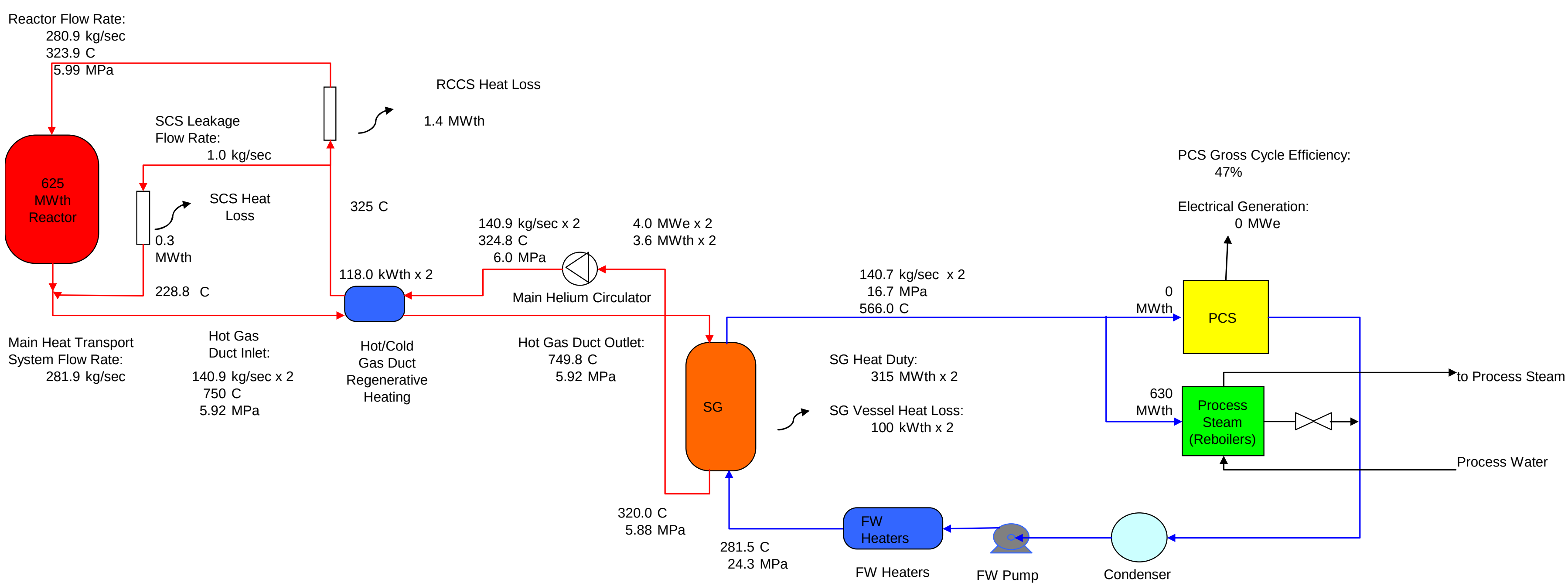

Figure 4-3: Heat Balance at Rated Power for 100% Process Heat Production

Table 4-2: Key Plant Parameters Resulting from the Point Design Heat Balances

Description	100% Electricity Production	50%/50% Electricity/Process Heat Production	100% Process Heat Production
Reactor			
Core Inlet Pressure	[5.99] MPa	[5.99] MPa	[5.99] MPa
Core Exit Pressure	[5.92] MPa	[5.92] MPa	[5.92] MPa
Active Core Flow Rate	[266.8] kg/sec	[266.8] kg/sec	[266.8] kg/sec
Core Bypass Flow Rate	[14] kg/sec	[14] kg/sec	[14] kg/sec
Reactor Flow Rate	[280.9] kg/sec	[280.9] kg/sec	[280.9] kg/sec
Main Heat Transport System			
Mass Flow	[281.9] kg/s	[281.9] kg/s	[281.9] kg/s
Main Helium Circulator Power Input	[3.6] MWth	[3.6] MWth	[3.6] MWth
Main Helium Circulator Power (each)	[4] MWe	[4] MWe	[4] MWe
HTS Internals Pressure Drop	[7] kPa	[7] kPa	[7] kPa
Main Helium Circulator Inlet Pressure	[5.88] MPa	[5.88] MPa	[5.88] MPa
Hot Gas Duct Exit Pressure	[5.92] MPa	[5.92] MPa	[5.92] MPa
Steam Generator Unit			
SG Heat Transfer (each)	[315] MWth	[315] MWth	[315] MWth
Gas Side Inlet Temperature	[749.8]°C	[749.8]°C	[749.8]°C
Gas Side Outlet Temperature	[320]°C	[320]°C	[320]°C
Gas Side Inlet Pressure (tube bundle)	[5.91] MPa	[5.91] MPa	[5.91] MPa
Helium Mass Flow Rate (each)	[140.9] kg/sec	[140.9] kg/sec	[140.9] kg/sec
Steam Side Flow Rate (each)	[140.7] kg/sec	[140.7] kg/sec	[140.7] kg/sec
Inlet Water Pressure	[24.3] MPa	[24.3] MPa	[24.3] MPa
Outlet Steam Pressure	[16.7] MPa	[16.7] MPa	[16.7] MPa
PCS			
Energy Input	[630] MWth	[315] MWth	[0] MWth
Electricity Production	[296] MWe	[148] MWe	[0] MWe
Process Heat			
Energy Input	[0] MWth	[315] MWth	[630] MWth

4.2 Other Heat Balances

As the conceptual design evolves, other heat balances will need to be performed for a combination of reactor power levels and cogeneration modes of operation covering the range of expected operating conditions.

5.0 CONCLUSIONS

This document has defined allocations and associated design margins as well as heat balances for the reference design described in the design baseline document [2]. Heat balances were performed to establish a self-consistent set of plant parameters.

6.0 REFERENCES

1. AREVA document 51-9106032-000, “NGNP Plant Design Requirements Document.”

2. AREVA document 51-9103803-001, “NGNP Conceptual Design Baseline Document for Conventional Steam Cycle for Process Heat and Cogeneration.”