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Pre-Construction Safety Report

Chapter 11

Steam and Power Conversion System

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11.1 List of Abbreviations and Acronyms

AAD	Startup and Shutdown Feedwater System [SSFS]
ABP	Low Pressure Feedwater Heater System [LPFHS]
ADG	Feedwater Deaerating Tank and Gas Stripper System [FDTGSS]
AHP	High Pressure Feedwater Heater System [HPFHS]
ALARP	As Low As Reasonably Practicable
APA	Motor Driven Feedwater Pump System [MFPS]
APC	Airplane Crash
APG	Steam Generator Blowdown System [SGBS]
ARE	Main Feedwater Flow Control System [MFFCS]
ASG	Emergency Feedwater System [EFWS]
ASP	Secondary Passive Heat Removal System [SPHRS]
ATE	Condensate Polishing System [CPS]
BFX	Fuel Building
BMX	Turbine Generator Building
BNX	Nuclear Auxiliary Building
BRX	Reactor Building
BSA	Safeguard Building A
BSB	Safeguard Building B
BPW	Circulating Water Pumping Station
CEX	Condensate Extraction System [CES]
CGN	China General Nuclear Power Corporation
CI	Conventional Island
CRF	Circulating Water System [CWS]
CWP	Circulating Water Pump
DBC	Design Basis Condition
DEC	Design Extension Condition
DiD	Defence in Depth
EDG	Emergency Diesel Generator
EMIT	Examination, Maintenance, Inspection and Testing

EPW	Explosion Pressure Wave
FLB	Feedwater Line Break
FLCV	Full Load Control Valve
FLIV	Full Load Line Isolation Valve
GCT	Turbine Bypass System [TBS]
GDA	Generic Design Assessment
HFE	Human Factors Engineering
HMI	Human Machine and Interface
HPR1000 (FCG3)	Hua-long Pressurised Reactor under construction at Fangchenggang nuclear power plant unit 3
HP	High Pressure
I&C	Instrumentation and Control
ISI	In-Service Inspection
LLCV	Low Load Control Valve
LLIV	Low Load Isolation Valve
LOCA	Loss of Coolant Accident
LP	Low Pressure
NC	Non-Classified
NDT	Non-Destructive Testing
NSSS	Nuclear Steam Supply System
NI	Nuclear Island
MCR	Main Control Room
MIV	Main Isolation Valve
MSIV	Main Steam Isolation Valve
MSL	Main Steam Line
MSSV	Main Steam Safety Valve
MSR	Moisture Separator Reheater
OPEX	Operating Experience
PCER	Pre-Construction Environmental Report
PCSR	Pre-Construction Safety Report
RCC-M	Design and Construction Rules for Mechanical Components of

	PWR Nuclear Islands
RCP	Reactor Coolant System [RCS]
REN	Nuclear Sampling System [NSS]
RGP	Relevant Good Practice
RHR	Residual Heat Removal
RIS	Safety Injection System [SIS]
RPE	Nuclear Island Vent and Drain System [VDS]
RPS	Reactor Protection System [RPS]
SA	Severe Accident
SAR	Instrument Compressed Air Distribution System [ICADS]
SBO	Station Black Out
SED	NI Demineralised Water Distribution System [DWDS(NI)]
SEK	Waste Fluid Collection System for Conventional Island [WFCSCI]
SEL	Conventional Island Liquid Waste Discharge System [LWDS (CI)]
SEN	Auxiliary Cooling Water System [ACWS]
SEP	Potable Water System [PWS (NI)]
SER	Conventional Island Demineralised Water Distribution System [CIDWDS]
SFC	Single Failure Criterion
SG	Steam Generator
SGN	Nitrogen Distribution System [NDS]
SGTR	Steam Generator Tube Rupture
SIT	Feedwater Chemical Sampling System [FCSS]
SIR	Chemical Reagents Injection System [CRIS]
SLB	Steam Line Break
SSC	Structures, Systems and Components
SSPB	Secondary Side Pressure Boundary
SVA	Auxiliary Steam Distribution System [ASDS]
UK HPR1000	UK version of the Hua-long Pressurised Reactor
UPS	Uninterruptible Power Supply
VDA	Atmospheric Steam Dump System [ASDS]

VLLCV	Very Low Load Control Valve
VPU	Main Steam and Drainage System for CI [MSDS]
VVP	Main Steam System [MSS]

System codes (XXX) and system abbreviations (YYY) are provided for completeness in the format (XXX [YYY]), e.g. Reactor Coolant System (RCP [RCS]).

11.2 Introduction

Chapter 11 presents the steam and power conversion system design of the UK version of the Hua-long Pressurised Reactor (UK HPR1000) nuclear power plant.

The secondary steam and power conversion system is a closed circuit.

There are three Steam Generators (SGs) and each SG connects through a separate main steam line to a common main steam header in the Turbine Generator Building (BMX). There are four steam lines downstream of the main steam header delivering the steam to the turbine High Pressure (HP) cylinder.

The steam from the SGs is passed through Main Steam System (VVP [MSS]) before entering the turbine hall into the HP cylinder. The exhaust steam from the HP cylinder is delivered to the Moisture Separator Reheaters (MSR), before the reheated steam is fed into the Low Pressure (LP) cylinders. The turbine exhaust steam at this stage is then condensed in the open circuit seawater-cooled condenser which is part of Circulating Water System (CRF [CWS]) that provides the heat sink for the unusable thermal energy in the cycle.

The condensate is pumped up from the condenser hotwell by condensate pumps, after which the Condensate Polishing System (ATE [CPS]) purifies the condensate to meet the secondary water chemistry specifications. The condensate then passes through the Low Pressure Feedwater Heater System (ABP [LPFHS]) and the Feedwater Deaerating Tank and Gas Stripper System (ADG [FDTGSS]). After its pressure is increased by the Motor Driven Feedwater Pump System (APA [MFPS]), the feedwater is further heated by the High Pressure Feedwater Heater System (AHP [HPFHS]) before it is delivered to the inlet of the steam generator through the Main Feedwater Flow Control System (ARE [MFFCS]), completing the secondary steam-water closed circulation.

The Startup and Shutdown Feedwater System (AAD [SSFS]) supplies feedwater to the SGs bypassing the AHP [HPFHS] during plant startup, hot standby and shutdown conditions.

When the turbine is unavailable, the steam produced by the steam generators could be dumped through the Turbine Bypass System (GCT [TBS]) directly to the condenser. The GCT [TBS] is also used to dump steam to the condenser during a fast load rejection (e.g. house load operation).

The Steam Generator Blowdown System (APG [SGBS]) helps maintain high quality secondary water chemistry quality under all plant operating conditions by removing concentrated impurities in the SGs.

The simplified diagram of the steam and power conversion system is presented in Appendix 11B Figure F-11B-1.

11.2.1 Chapter Route Map

The **Fundamental Objective** of the UK version of the Hua-long Pressurised Reactor (UK HPR1000) is presented in Chapter 1 - "*The Generic UK HPR1000 can be constructed, operated, and decommissioned in the UK on a site bounded by the generic site envelope in a way that is safe, secure and that protects people and the environment.*"

In order to achieve the fundamental objective, five high level claims and several decoupled low level claims are defined in Chapter 1. The claims related to the steam and power conversion system are **Claim 3** (Level 1) and **Claim 3.3** (Level 2):

a) ***Claim 3*** *- The design and intended construction and operation of the UK HPR1000 will protect the workers and the public by providing multiple levels of defence to fulfil the fundamental safety functions, reducing the nuclear safety risks to a level that is as low as reasonably practicable.*

b) ***Claim 3.3*** *- The design of the processes and systems has been substantiated and the safety aspects of operation and management have been substantiated*

Chapter 11 is intended to support **Claim 3.3**. In order to support this level 2 Claim, a Level 3 Claim is developed for the steam and power conversion system as identified below:

Claim 3.3.7: The design of the Steam & Power Conversion System has been substantiated.

Therefore, the main objective of Chapter 11 is to present the design information of the steam and power conversion system in the UK version of the Hua-long Pressurised Reactor (UK HPR1000) nuclear power plant to support ***Claim 3.3.7***.

The ***Route Map*** intended to set out a "direction of moving forward" for Chapter 11 is developed and presented in Appendix 11A.

The steam and power conversion system contains many subsystems， which can be divided into two categories: safety related and non-safety related. Claim 3.3.7 is only applicable for the safety related systems described in Sub-chapter 11.3. For the non-safety related system, only general information of the system design is provided in Sub-chapter 11.4.

11.2.2 Chapter Structure

The structure of the Pre-Construction Safety Report (PCSR) Chapter 11 is as follows:

a) Sub-chapter 11.1 - lists all the Abbreviations and Acronyms presented in this chapter;

b) Sub-chapter 11.2 - introduces the Route Map, chapter structure, chapter interfaces and general design requirements;

c) Sub-chapter 11.3 - presents the demonstration of Steam and Power Conversion System (Safety Related) design;

d) Sub-chapter 11.4 - presents the description of Steam and Power Conversion System (Non-Safety Related) design;

e) Sub-chapter 11.5 - presents a general conclusion for the system and component design;

f) Sub-chapter 11.6 - presents all the available references presented in this chapter;

g) Appendix 11A - presents the Route Map of Sub-chapter 11.3;

h) Appendix 11B - presents the simplified flow diagram of systems;

i) Appendix 11C - presents all of the tables.

11.2.3 Interfaces with other Chapters

Chapter 11 of the PCSR mainly contains two parts, safety related and non-safety related, which have different interfaces with other chapters. The interfaces between this chapter with respect to safety related and non-safety related systems, and other chapters can be found in Sub-chapters 11.3.1 and 11.4.1 respectively.

11.2.4 General Design Requirements

A number of engineering principles have been identified and shall be considered in system design. These design requirements and principles are mainly derived from Chapters 4, 15, 18, 19, 21, 24, 30 and 31. Moreover, there are further requirements or principles presented in Reference [2], [3], [4], [5] and [6].

These requirements / principles are summarised as stated below:

a) Safety Classification;

b) Engineering Design Requirements:

1) The Reliability Design of Structures, Systems and Components (SSC):

- Single Failure Criterion (SFC);
- Independence;

- Diversity;
- Fail-Safe;
- Ageing and Degradation.

2) Human Factors;
3) Autonomy.
4) Other design requirements.

c) Equipment Qualification;

d) Protection Design against Internal and External Hazards;

e) Commissioning and Testing;

f) Examination, Inspection, Maintenance and Testing;

g) Thermal-Hydraulic Phenomena;

h) Material Selection;

i) Insulation;

j) Decommissioning.

The general design requirements section is just presented for information and does not represent all the design requirements placed upon the system.

11.2.4.1 Safety Classification

The aim of the classification is to help ensure that the item is designed, manufactured, constructed, commissioned and operated according to appropriate requirements so as to achieve good quality under all expected operating conditions and realise the safety functions.

11.2.4.2 Engineering Design Requirements

<u>The Reliability Design of SSC</u>

a) Single Failure Criterion

The SFC is considered to ensure that more than the minimum of components are provided to carry out a safety function [2]. The criterion is applicable to mechanical systems that perform a safety function, such that it must be capable of performing its intended safety function in the presence of any single failure. It is beneficial to ensuring the high reliability of systems and to maintaining the plant within its deterministic design basis. The redundancy design helps satisfy this criterion.

The single failure includes active and passive failures:

1) An active single failure is defined as a failure which is sufficient to invalidate the relevant safety function of a component, including the malfunction of a mechanical or electrical component which relies on mechanical movement to complete its intended function upon demand, and the malfunction of an Instrumentation and Control (I&C) component;

2) A passive single failure is defined as a failure which could occur in a component that does not change its state while realizing its function. The passive single failure at the start of a transient should be assessed in an appropriate means.

The SFC is applied to F-SC1 systems in the system level and F-SC2 systems in the function level, thus redundancy is needed in the design of these systems. Consideration of the single failure criteria at the system level of F-SC1 indicates that these systems must be redundant. Consideration of the single failure criteria at the function level for systems fulfilling F-SC2 functions indicates that these systems may not require redundancy.

b) Independence

In addition to the high level principle of independence between levels of Defence in Depth (DiD), the following principles for independence should be applied in the design to achieve system reliability and tolerance to faults [2]:

1) Independence between the trains of redundant systems should be maintained as far as reasonably practicable (avoidance of common cause failure);

2) Independence between components of different safety categories should be maintained as far as reasonably practicable (avoidance of impact on the component of higher safety category from an item of lower safety category);

3) The components designed to mitigate a potential initiating event should be independent from the effects of this potential initiating event as far as reasonably practicable.

Independence is accomplished in the design of systems by using functional isolation and/or physical separation. Functional isolation is used to reduce adverse effects between elements of connected systems or systems redundantly designed. These adverse effects may be caused by the normal operation, abnormal operation or failure of any part of these systems.

Physical separation should be applied in the layout of systems as far as reasonably practicable, to reduce the potential of common cause failure due to a localised initiating event. The choice of isolation measures (compartmentalisation, distance, orientation etc.) should take into account the nature of the initiating events.

c) Diversity

To reduce the potential of common cause failure, diversity should be realised by incorporating different attributes into the design of systems or components, as appropriate, in the redundant systems or components that perform the same safety function. The nuclear auxiliary systems shall consider the requirement of diversity [2].

In order to achieve the reliability targets and to fulfill the DiD concept, diversity should be realised by incorporating different attributes into the design of systems or components, as appropriate, in the redundant systems or components that perform the same safety function. Such attributes can be different operating principles, different physical variables, different operating conditions, different manufacturers, etc.

Common cause failure of safety measures should be assumed in the analysis for frequent faults. Therefore, a main protection line and a diverse protection line should be established to achieve the fundamental safety objective for frequent faults.

What should be paid special attention is that the diversity should be taken into account in the design of systems performing Safety Category 1 Functions (FC1) or Safety Category 2 Functions (FC2) based on software to avoid common cause failure.

d) Fail-Safe

According to Reference [2], the fail-safe requirements should be considered and incorporated, as appropriate, into the design of systems and components important to safety, so that their failure or the failure of a support feature will not invalidate the performance of the intended safety function.

e) Ageing and Degradation

The general design requirements and management of ageing and degradation are shown in Chapter 4 and Chapter 31.

Ageing and degradation (asset management) includes several aspects, such as equipment qualification, state monitoring, pre-service inspection, commissioning tests, operating and Examination, Maintenance, Inspection and Testing (EMIT), decommissioning, etc.

The design life of items important to safety at a nuclear power plant shall be determined. Appropriate margins shall be provided in the design to take due account of relevant mechanisms of ageing, neutron embrittlement and wear out and of the potential for age related degradation, to ensure the capability of items important to safety to perform their necessary safety functions throughout their design life, including testing, maintenance, maintenance outages, plant states during a postulated initiating event and plant states following a postulated initiating event.

Provision shall be made for monitoring, testing, sampling and inspection to assess ageing mechanisms predicted at the design stage and to help to identify unanticipated behaviour of the plant or degradation that might occur in service.

The ageing effects concerning individual components have been taken into consideration in the system design:

1) Sufficient margin has been made to avoid failures caused by ageing effects in the component design;

2) Practical examining measures are planned to address the ageing effects during plant operation (EMIT);

3) For replaceable parts of components, replacement plans and layout designs are properly considered.

<u>Human Factors</u>

According to Reference [2], the design shall allocate functions properly, support personnel in the fulfilment of their responsibilities and in the performance of tasks. The design also needs to identify human actions that may affect safety and proportionately analyse all tasks important to safety, and limit the likelihood of operational errors and their impact on safety.

Moreover, the design of systems, components, layouts, Human Machine and Interface (HMI) and operator working environments shall meet the human factor requirements which are presented in the safety case of human factors (start from Chapter 15). The design result of systems will be further assessed by the Human Factors Engineering (HFE) task analysis.

<u>Autonomy</u>

According to Reference [2], autonomy can be separated into:

a) Autonomy in respect to operators

If the plant selected parameters exceed set points, the protection system shall come into action, providing automatic scram and initiation of post-trip cooling. The plant shall be designed in such a way that it meets the following autonomy objectives:

1) The numerical targets of DBC-2, DBC-3, DBC-4 and DEC-A can be met without operator action from the Main Control Room (MCR) in less than 30 minutes from the first significant signal;

2) The numerical targets of DBC-2, DBC-3, DBC-4 and DEC-A can be met without action outside the MCR in less than 1 hour from the first significant signal;

3) No site based mobile light equipment shall be required in less than 6 hours from accident initiation, for core damage prevention actions in DEC;

4) No site based mobile light equipment shall be required in less than 12 hours from accident initiation, for containment performance assurance in DEC;

5) No offsite or onsite mobile heavy equipment is required in less than 72 hours in both DBCs and DECs;

6) In addition, the containment system shall be designed in such a way that it can withstand any of the severe accidents considered in DEC, without operator action during the first 12 hours from the beginning of the severe accident conditions.

b) Autonomy in respect to the heat sink

Design provisions shall ensure adequate decay heat removal under DBC and DEC, for 72 hours without external support. The initial means ensure decay heat removal shall last at least 24 hours.

The design shall include provisions allowing additional means to ensure decay heat removal after 72 hours.

c) Autonomy in respect to power supply systems.

1) Electrical Power Supply

The period of independence of the installation in relation to external electrical power supplies shall be at least 72 hours; this applies to DBC and DEC.

The plant shall have an available power supply unit which is independent of the electrical power supply units designed for operational conditions and postulated accidents. It shall have sufficient capacity to support at the same time all these functions: remove decay heat, ensure primary circuit integrity, maintain reactor sub-criticality and monitor the unit state.

The batteries which perform FC1 and FC2 functions shall be sized so that their expected autonomy is at least 2 hours following any DBC, without recharging.

The batteries which perform significant safety functions shall be sized so that their expected autonomy could be 12 hours in severe accident without recharging.

2) Compressed Air

Where required to support essential systems, the availability of compressed air reserves should be sufficient to be consistent with the timescale for the availability of the equipment.

<u>Other Design Requirements</u>

In the design of systems, the influence of harmful system interactions and disturbances in the electrical power grid stated in Chapter 4 shall be considered.

a) Prevention of Harmful Interactions of Systems Important to Safety

According to Reference [2], the protection of interfacing systems shall be considered in systems design.

The potential for harmful interactions of systems important to safety at the nuclear power plant that might be required to operate simultaneously shall be evaluated, and the effect of any harmful interactions shall be prevented.

In the analysis of the potential for harmful interactions of systems important to safety, due account shall be taken of physical interconnections and of the possible effects of one system's operation, maloperation or malfunction on local environmental conditions of other essential systems, to ensure that changes in environmental conditions do not affect the reliability of systems or components in functioning as intended.

If two fluid systems important to safety are interconnected and are operating at different pressures, either the systems shall both be designed to withstand the higher pressure, or provision shall be made to prevent the design pressure of the system operating at the lower pressure from being exceeded.

b) Considerations Related to the Electrical Power Grid

According to Reference [2], the functionality of items important to safety at the nuclear power plant shall not be compromised by disturbances in the electrical power grid.

11.2.4.3 Equipment Qualification

According to Reference [2], equipment qualification shall be implemented to verify that items important to safety are capable of performing their intended functions when necessary, and in the environmental conditions including the variations in ambient environmental conditions that are anticipated in the design for the plant.

Equipment qualification includes environmental and seismic qualification. Considering the results of fault analysis and the safety classifications, the specific equipment to be qualified is listed as follows:

a) Equipment required for environmental qualification:

All normal operation, fault and accident conditions should be considered in the equipment qualification process. Normal operational conditions should consider the lifetime of the equipment and the environment of the normal condition in the plant where the equipment is located. The variation of environmental condition arising from the fault and accident conditions should be considered in the environmental qualification.

1) Mechanical equipment and electrical equipment that perform FC1 or FC2 functions;

2) Mechanical equipment and electrical equipment that perform Safety Category 3 Functions (FC3) are required:

- To maintain a safe state;

- To protect against DEC-A and mitigate DEC-B.

b) Equipment required for seismic qualification:

The equipment that performs the following functions should be seismically qualified: operability (O), functionality (F), integrity (I) or stability (S).

The parameters which are related to the environmental conditions and their impact on equipment are presented below:

a) Temperature

Temperature can indirectly change the performance of the equipment by gradual chemical and physical processes, which is also called thermal aging.

b) Pressure

Pressure and its rapid changes can affect the performance of equipment by exerting additional forces on the equipment. A high increase of external or internal pressure may cause structural failure of the fully sealed equipment. The rapid increase of pressure may cause structural failure of the imperfectly sealed equipment.

c) Radiation

Nuclear radiation could induce changes in the atomic and molecular structure of matter through excitation, oxidation, crosslinking, degradation and shearing processes, resulting in the change of equipment performance. Some changes improve the performance of the equipment, but most of the changes cause a decline in the performance.

There exist four main types of radiation (α, β, γ and neutron) in nuclear power plants. γ radiation possesses a very high capacity for penetration. On the contrary, the penetration capacity of β radiation is low, 1mm steel or a 10mm water layer can shield most of the β radiation. The penetration capacity of α radiation is even lower than β radiation. Neutron radiation is considered for equipment near the reactor pit.

d) Humidity

Humidity (high humidity) can directly lead to equipment performance degradation, and can make other environmental conditions worse. For example, moisture could lead to corrosion and current effects at the interfaces of different metals. Moisture could directly reduce the performance of organic materials, degrading their physical, mechanical and electrical performance and deforming them. Moisture on the surface can significantly reduce the insulation resistance and breakdown voltage of the insulating surface.

The environmental conditions of equipment qualification will be defined according to the result of the fault analysis. The methods of equipment qualification are presented below:

a) Type test under representative conditions, in accordance with an appropriate test standard;

b) Qualification by analysis:

  1) Calculation (design analysis), usually structural load analysis and mechanical analysis in accordance with an appropriate design code;

  2) Operating experience based;

  3) Analogy - by comparison with similar qualified equipment.

11.2.4.4 Protection against Internal and External Hazards

According to Chapter 4 and further information which is presented in Reference [2], the necessary capability, reliability and functionality of items important to safety shall be ensured in the conditions arising from internal and external hazards to deliver the relevant safety functions. The design principles relevant to the hazards are presented in Chapters 18 and 19.

The types of hazards have been identified in Reference [6] for both internal hazards and external hazards.

11.2.4.5 Commissioning

The equipment that performs safety functions shall be effectively demonstrated via commissioning before service.

The system commissioning programme shall be established to guide the commission test onsite. The commission content, phased approach and scope are shown in Chapter

30. The requirements, approach of commissioning presented in Chapter 30 shall be considered in systems design.

The commissioning programme phases have been identified for the UK HPR1000 in Chapter 30. The main test stages can be separated as shown below:

a) Stage I: Preliminary Test Period

b) Stage II: Functional Tests Period

c) Stage III: Initial Startup Test Period

11.2.4.6 Examination, Inspection, Maintenance and Testing

According to the requirements which are defined in Chapter 4, the design should be such that activities for EMIT are facilitated for the purpose of maintaining the capability of SSC important to safety to perform essential safety functions, so as to satisfy the reliability requirement.

The above activities are specified taking into account the design code requirements, reliability analysis and potential degradation mechanisms, commensurate with the safety class of the system.

Examination and Inspection

In-Service Inspection (ISI) is a preventive maintenance process involving the use of Non-Destructive Testing (NDT) for nuclear pressure mechanical components at scheduled intervals during operation. ISI will be used to detect the anticipated degradation in good time before it compromises structural integrity, and confirm the absence of unanticipated degradation that could lead to failure. More information is presented in Chapter 31.

Maintenance

According to Chapter 31, the purpose of maintenance activities is also to enhance the reliability of equipment. The range of maintenance activities includes servicing, overhaul, repair and replacement of parts, and often, as appropriate, tests, calibration and inspection.

The maintenance types, safety requirements and maintenance strategy are presented in Chapter 31.

Periodic Testing

According to Chapter 31, the goal of the periodic test design is to define a comprehensive list of the periodic tests that are to be performed on a given system. Each periodic test defines:

a) The test content and scope;

b) The test frequency;

c) The operating mode during which the test is to be performed.

These periodic tests are used to ensure the safety functional availability of a given system. The types of periodic tests, relevant requirements and the methodology of completeness analysis are presented in Chapter 31.

11.2.4.7 Special Thermal-Hydraulic Phenomena

Based on the feedback from the operating plant, there may be some special Thermal-hydraulic phenomena during standby or operation of the system. These Thermal-hydraulic phenomena may induce potential risk for the safe operation of the facility.

These hydraulic phenomena are identified and presented as shown below (including but not limited to):

a) Phenomenon regarding the dead leg;

b) Phenomenon regarding the hot water and cold water mixing;

c) Phenomenon regarding the thermal stratification;

d) Phenomenon regarding the water hammers;

e) Phenomenon regarding the boiler effect.

11.2.4.8 Material Selection

Material selection of systems and equipment is one of the most significant factors for the safety and economy fo the nuclear power plant, and therefore special attention shall be paid to the material selection at the design stage for SSC to carry out their duties with high reliability throughout the design life of the plant.

The principles and the approach of material selection are presented in Reference [15], and shall be considered in system design. These general principles related to the material selection are summarised as below:

a) Material selection shall be consistent with the functional objectives of the system and equipment;

b) Material selection shall be performed in a manner in which the classification shall be reflected; requirements shall be commensurate with the classification;

c) Materials selected for use in systems shall be compatible with the full range of environmental conditions which may be encountered over the plant design life;

d) Materials selected for use in systems shall present high functional reliability and good resistance to aging and degradation throughout the design life to mitigate the risk of performance degradation and failure of SSC;

e) Materials selected for use in systems shall possess excellent manufacturability, and shall be convenient for performing processing sequences such as forging or casting, machining, heat treatment, welding and inspection;

f) Operating Experience (OPEX) and Feedback shall be taken into account for the material selection of systems. The proven material is preferred, and novel material (without been proved) or hazardous material is prohibited;

g) Generation and transportation of source terms shall be specially considered when selecting the material to be used in systems, intended to minimise the radiological dose to workers and the public when performing in-service inspection, maintenance, replacement and decommissioning.

In addition to the above factors, the selection of materials also needs to consider the influence of the water chemistry.

11.2.4.9 Insulation

During the equipment and piping system insulation design, the following issues must be paid attention to:

a) During plant normal operation without any maintenance work to be carried out, the insulation design shall reduce the heat loss as much as possible to save energy;

b) During plant maintenance or refuelling, the insulation design shall protect the workers from being scalded;

c) During plant maintenance or refuelling, the insulation design shall ensure the convenience of installation or replacement;

d) Moreover, flammable material is prohibited to prevent potential internal hazards.

11.2.4.10 Decommissioning

Decommissioning shall be considered during the design stage for the UK HPR1000. At the current stage, the general considerations of decommissioning are mentioned in Chapter 24 and mainly include:

a) Consideration of facilitating decommissioning;

b) Consideration of the decommissioning strategy; and,

c) Consideration of the preliminary decommissioning plan for the UK HPR1000.

11.3 Steam and Power Conversion System (Safety Related)

11.3.1 Introduction

11.3.1.1 Sub-Chapter Route Map

Sub-chapter 11.3 mainly demonstrates the systems which are related to nuclear safety. These systems include the:

a) Main Steam System (VVP [MSS]);

b) Main Feedwater Flow Control System (ARE [MFFCS]);

c) Steam Generator Blowdown System (APG [SGBS]).

A ***Route Map*** intending to sets out a "direction of moving forward" for this sub-chapter is identified and is presented in Appendix 11A.

11.3.1.2 Sub-Chapter Structure

The general structure of Sub-chapter 11.3 is presented below:

a) Sub-chapter 11.3.1 - introduces the Route Map, sub-chapter structure and chapter interfaces;

b) Sub-chapter 11.3.2 - presents the relative codes and standards which are intend to be used in the UK HPR1000 VVP [MSS], ARE [MFFCS], APG [SGBS] and their component design;

c) Sub-chapter 11.3.3 - presents the information of VVP [MSS] design;

d) Sub-chapter 11.3.4 - presents the information of ARE [MFFCS] design;

e) Sub-chapter 11.3.5 - presents the information of APG [SGBS] design;

f) Sub-chapter 11.3.6 - presents the brief As Low As Reasonably Practicable (ALARP) demonstration for the VVP [MSS], ARE [MFFCS] and APG [SGBS];

g) Sub-chapter 11.3.7 - presents a general conclusion for the system and component design;

11.3.1.3 Interfaces with Other Chapters

The Pre-Construction Safety Report (PCSR) contains various chapters, a number of which contain design information. To help understand the relationship between this sub-chapter and other chapters, the relevant interfaces have been identified and are presented in Table T-11C-1 of Appendix 11C. Moreover, this sub-chapter can also provide a brief design introduction such as system functions, configuration as well as operation for the Pre-Construction Environmental Report (PCER) where the system and component need to be discussed.

11.3.2 Applicable Codes and Standards

The general principle relevant to the selection of appropriate standards is presented in Chapter 4 and Reference [2]. Moreover, the principle is presented in detail in Reference [3].

Wherever possible, the standards applied for the engineering substantiation should be:

a) Internationally recognised in nuclear industry;

b) The latest or currently applicable approved standards; and

c) Consistent with the plant reliability goals necessary for safety.

Based on the principles mentioned above, the applicable codes and standards which are intended to be selected and used in UK HPR1000 design are identified in Reference [17]. Therefore, the applicable codes and standards for the VVP [MSS], ARE [MFFCS] and APG [SGBS] system and main components design are presented in Table T-11C-2 and in Reference [7], [8] and [11].

Currently, the work of conformity analysis and gap analysis of the codes and standards is continuing, { }.

11.3.3 Main Steam System

11.3.3.1 Safety Functional Requirements

11.3.3.1.1 Control of reactivity

The VVP [MSS] does not perform the reactivity control function directly [7].

However, the VVP [MSS] shall be used to prevent potential over-cooling or dilution of the RCP [RCS] to support the reactivity control function [7]:

a) In the case of excessive increase in steam flow events, the VVPs [MSS] automatic isolation of the Main Steam Line (MSL) contributes to prevent core overcooling and thus to control reactivity;

b) In the case of Steam Generator Tube Rupture (SGTR) conditions, with no reactor coolant pump in operation and with a failure of the Atmospheric Steam Dump System (VDA [ASDS]) train of the affected SG, the VVP [MSS] shall allow for depressurisation of the affected SG in order to minimise the reverse flow into the Reactor Coolant System (RCP [RCS]). Thus limiting the risks of return to core criticality by dilution.

11.3.3.1.2 Removal of heat

The VVP [MSS] performs the heat removal function as identified below [7]:

a) During plant power operation, the VVP [MSS] shall ensure continuous heat removal from the RCP [RCS] by steam transfer to the steam turbine;

b) During plant normal shutdown, after the reactor has been switched off, the VVP [MSS] shall remove residual heat from the RCP [RCS] to the condenser;

c) In the case of Design Basis Condition (DBC) 2-4 events, or Design Extension Condition A (DEC-A) events, the VVP [MSS] shall ensure the heat of the RCP [RCS] can be removed. This is achieved by the VVP [MSS] and the condenser, or the VDA [ASDS] if the condenser is unavailable.

11.3.3.1.3 Confinement

The VVP [MSS] performs the confinement function as identified below [7]:

a) In the case of SGTR, the VVP [MSS] shall isolate the affected SG to confine the contaminated fluid as an extension of the SG;

b) During Severe Accidents (SA), the VVP [MSS] participates in the isolation of containment.

11.3.3.1.4 Extra Supporting Function

The design of the VVP [MSS] shall support the control of reactivity, removal of heat and confinement functions via providing necessary plant information, providing mechanical supporting functions and providing other supporting functions.

Moreover, the design of the VVP [MSS] shall prevent, protect and mitigate the hazard impact of internal and external hazards.

Therefore, the VVP [MSS] performs the following extra supporting functions [7]:

a) Monitoring the operational parameters of steam produced by SGs;

b) Monitoring the ambient conditions in the VVP [MSS] valve compartment;

c) Contribution to over-pressure protection of the Secondary Side Pressure Boundary (SSPB).

Moreover, the states of components which perform important safety functions shall be monitored.

11.3.3.2 Design Requirements

The engineering design requirements are integrated and introduced in Sub-chapter 11.2.4. Each engineering design requirement is analysed and the applicable items are identified for the VVP [MSS]. The detail information is presented in [7] and [18].

The following principles are not applicable for the VVP [MSS]:

a) Autonomy in Respect to the Heat Sink

The VVP [MSS] is not a heat sink system. Therefore this principle is not applicable for the VVP [MSS].

b) Autonomy in Respect to Power Supply Systems

This principle is mainly used in the power supply systems design and is not applicable for the VVP [MSS].

c) Considerations Related to the Electrical Power Grid

The VVP [MSS] does not include pumps and other equipment affected by the power grid.

11.3.3.3 Design Bases

This Sub-chapter aims to provide the design bases for the VVP [MSS]. These design bases are derived from the safety requirements and are used for further equipment sizing.

Two kinds of assumption are provided as shown below:

a) General Assumptions

The general assumptions are mainly derived from the design requirements presented in Sub-chapter 11.3.3.2. The applicable principles which may affect the equipment sizing and the relevant assumptions are demonstrated in Sub-chapter 11.3.3.3.1.

b) Design Assumptions

The design assumptions are mainly derived from the safety functional requirements presented in Sub-chapter 11.3.3.1. These assumptions are demonstrated in Sub-chapter 11.3.3.3.2.

11.3.3.3.1 General Assumption

Safety Classification

The MSL isolation function is used to achieve the controlled state during DBC2-4 conditions. Therefore, the function classification of isolation is FC1.

The function classification of transferring steam from the SG to the Secondary Passive Heat Removal System (ASP [SPHRS]) is FC3.

The classification of the VVP [MSS] safety functions is listed in Table T-11C-5 and Reference [7].

Ageing and Degradation

The main components of the VVP [MSS] are designed for the 60 years plant operation. These components mainly include:

a) MSLs;

b) Main Steam Isolation Valves (MSIVs);

c) Main Steam Safety Valve (MSSVs).

During system and equipment design, the ageing and degradation of the equipment which is important to safety must be taken into account.

Moreover, the ageing effects on sensors such as drift shall be considered. This is applied in monitoring control function design.

Equipment Qualification

Active components of the VVP [MSS] that perform FC1 safety functions shall be qualified.

Hazards

Hazards may induce an environmental condition change in the compartment where the equipment is located. Moreover, safety functions such as the confinement function shall be performed under earthquake events. Therefore, the equipment design shall take the effects of hazards into account to ensure the ability of the safety function.

11.3.3.3.2 Design Assumption

Control of Reactivity

During normal operation, the VVP [MSS] does not participate in the reactivity control function [7].

In the case of excessive increase in steam flow events, the VVP [MSS] shall contribute to prevent core overcooling. Functional requirements for the VVP [MSS] are:

a) Safety functions are performed by Main Steam Isolation Valves (MSIVs) which are used for isolating the Main Steam Lines (MSLs);

b) Limiting the MSIVs stock time of closing to no more than 5 seconds.

In the case of SGTR conditions, with no reactor coolant pump in operation and with a failure on VDA [ASDS] train of the affected SG, the VVP [MSS] shall allow depressurisation of the affected SG through the VDA [ASDS] of another SG in order to minimise the reverse flow into the RCP [RCS]. Thus limiting the risk of return to core criticality by dilution.

Removal of Heat

In power operation, the VVP [MSS] shall ensure continuous heat removal from the RCP [RCS] by steam transfer to the turbine.

During plant normal shutdown, the heat of the RCP [RCS] is transferred to the heat sink (e.g. condenser or VDA [ASDS] if the condenser is unavailable) via the VVP [MSS] until the Safety Injection System (RIS [SIS]) is connected in Residual Heat

Removal (RHR) mode.

In the case of DBC2-4 events, while heat extraction by the secondary circuit is required to reach the controlled state and/or the safe state, the VVP [MSS] and VDA [ASDS] (or the condenser if available) shall remove residual heat and cool the RCP [RCS] by dumping steam into the atmosphere (respectively into the condenser).

Under Loss of Coolant Accident (LOCA) or SGTR accident conditions, the VVP [MSS] and VDA [ASDS] shall remove the decay heat to the atmosphere in order to limit the primary coolant leak, and to ensure the safety injection can be performed by the RIS [SIS].

In case of DEC-A events, while heat extraction by the secondary circuit is required to reach the final state, the VVP [MSS] shall transfer the steam to the condenser (if the condenser is available) or to the atmosphere via the VDA [ASDS] (if the condenser is not available) in order to remove heat to cool the RCP [RCS].

Confinement

To limit radioactive releases to the environment in case of DBC and DEC events, the VVP [MSS] shall participate in the containment of radioactive materials by performing the following functions:

a) In the case of SGTR, it shall confine the contaminated fluid as an extension of the SG by isolation of the affected SG;

b) In the case of excessive pressure rise, it shall ensure SSPB overpressure protection by steam discharge through the MSSVs in order to ensure its integrity and secure its containment extension role.

Extra Supporting Function

The extra supporting functional requirements of the VVP [MSS] are:

a) Monitoring the ambient condition (i.e. temperature) in the compartment where the main VVP [MSS] valves are located;

b) The Main Steam Safety Valves (MSSVs) are set to perform over-pressure protection for the secondary pressure retaining boundary. The MSSV shall be designed that [19]:

    1) Provide a minimum flowrate:

    At least 27% of the nominal steam flow rate at the design pressure of 8.9 MPa(g);

    2) Set points of MSSVs:

    9.1 MPa(g) for the first MSSV and 9.3 MPa(g) for the second MSSV.

The important system operation parameters such as steam pressure, steam flowrate as well as steam temperature shall be monitored.

The opening / closing states of the MSSV and MSIV shall be monitored and indicated to the operator.

11.3.3.4 System Description and Operation

11.3.3.4.1 System Configuration

The VVP [MSS] consists of the pipes and valves that transfer the steam from each SG to a common main steam header in the turbine building. Each main steam line connects to a SG and passes through the containment boundary into a safeguard building before it reaches the turbine building.

A summarised introduction for the VVP [MSS] is presented in Reference [20]. More detailed design information is presented in Reference [19].

11.3.3.4.2 Main Equipment

Main Steam Line (MSL)

The MSL participates in transferring heat to the ultimate heat sink and limiting radioactive releases. Therefore, the MSL is safety classified and designed according to the code of *Design and Construction Rules for Mechanical Components of PWR Nuclear Islands* (RCC-M).

The design pressure and temperature are the same as the secondary side of the SG. The material of the steam line is suitable for both environmental and steam operating conditions, and ensures the fewest further induced hazards.

More detailed information is presented in Reference [19].

Main Steam Isolation Valve (MSIV)

The MSIV performs the main steam isolation function in DBC condition. The closure time of the MSIV is derived from the accident analysis.

The MSIV is a wedge gate valve fitting with an oleo-pneumatic actuator, which is designed according to the RCC-M code.

The actuator of the MSIV consists of a piston, a chamber filled with compressed nitrogen and a hydraulic fluid loop. The hydraulic fluid loop contains two redundant drainage manifolds connected to the lower chamber. One of the manifolds is connected to an oil pump which delivers oil into the lower chamber to move the piston and open the valve.

The general parameters of the MSIV are shown in Table T-11C-3. More detailed information is presented in Reference [19].

Main Steam Safety Valve (MSSV)

The MSSV is a spring-loaded safety valve, providing overpressure protection for the SG secondary side, which is designed according to RCC-M Section I. Each of the MSLs is fitted with two MSSVs located between the containment penetration and the MSIV.

The general parameters of the MSSV are shown in Table T-11C-4. More detailed information is presented in Reference [19].

11.3.3.4.3 Main Layout

The following factors needs to be considered during system layout design of the VVP [MSS], such as external and internal hazard protection, radiological protection, layout requirements for equipment, piping, special thermal-hydraulic phenomena as well as examination, maintenance and replacement, special system consideration, operating experience, etc.

The main components of the VVP [MSS] are arranged in the Reactor Building (BRX) and safeguard building to ensure that the three main steam lines are physically separated from each other.

The arrangement of VVP [MSS] components and pipes has considered installation, maintenance, replacement and protection against internal hazards.

More detailed information is presented in Reference [18].

11.3.3.4.4 System Interface

The system interface can be separate into two groups:

a) Supporting systems: which providing supporting functions to the VVP [MSS] in order to ensure the safety or operational functions performed by the VVP [MSS];

b) User systems: which are served by the VVP [MSS] (via supplying cooling water) to ensure their safety or operational functions.

The main supporting systems of the VVP [MSS] are as identified below:

a) VDA [ASDS];

b) ASP [SPHRS];

The main user systems of the VVP [MSS] are as identified below:

a) RCP [RCS];

b) Main Steam and Drainage System for CI (VPU [MSDS]).

More detailed information of the interfacing systems and functional requirements is presented in Reference [19].

11.3.3.4.5 System Instrumentation and Control

Automatic control

The MSIVs are kept open during normal operation, and the VVP [MSS] does not receive automatic control signals.

Under accident conditions, the MSIVs close automatically at the isolation signal from the Reactor Protection System (RPS [RPS]).

Information to the Operator

The information available to the operator in the Main Control Room (MCR) for each VVP [MSS] train is as follows:

a) Pressure inside MSL;

b) Flow rate of steam;

c) The position of MSIVs;

d) The configuration of the MSIV actuator.

More detailed information of VVP [MSS] control function design is provided in Reference [12].

11.3.3.4.6 System Operation

Plant Normal Condition

The VVP [MSS] is in steady state during reactor power operation, transferring the steam generated by the SG to the turbine.

Before startup of the turbine unit, the steam generated by the SG is discharged to the condenser through the GCT [TBS] to maintain the load balance of the nuclear island and conventional island.

During plant shutdown, the heat generated by the RCP [RCS] is removed by the GCT [TBS]. The water level of the SG is controlled by the ARE [MFFCS] and supplied by the AAD [SSFS]. If the condenser is unavailable, the heat of the RCP [RCS] is taken away through the VDA [ASDS].

After the RIS [SIS] connects to the RCP [RCS] in RHR mode to remove the primary heat, at least two SGs shall be maintained to be available. Therefore, the relevant trains of the VVP [MSS] and VDA [ASDS] corresponding to the two available steam generators shall be in standby state.

More information relevant to system operation is presented in [12].

Plant Fault or Accident Condition

In the case of Design Basis Conditions (DBC) and Design Extension Conditions

(DEC), the isolation of steam lines can prevent the release of radioactive materials to the environment.

The excessive increase of steam flow leads to an increase of heat removal from the RCP [RCS] and uncontrolled SG depressurisation. Main steam isolation can be triggered by the RPS [RPS]. The MSIVs closes automatically to prevent overcooling of the RCP [RCS].

In Feedwater Line Break (FLB), the affected SG is depressurised and the water inventory decreases. The feedwater flow rate towards the other two unaffected SGs will decrease since the feedwater lines are connected to a feedwater header. Both low SG pressure and high SG pressure drop trigger main steam isolation and main feedwater isolation. The MSIVs close automatically at the signal from the RPS [RPS].

Steam Line Break (SLB) accidents lead to the overcooling and depressurisation of the affected SG. The break will also lead to containment overpressure if it is in the Reactor Building (BRX). All MSIVs will close if the SG pressure is low, SG pressure drop is high, or the containment pressure is high.

Under SGTR accident conditions, the MSIV automatically isolates the affected SG to prevent radioactive material release to the environment directly.

More information relevant to system operation under plant accident as well as system failure or malfunction is presented in Reference [12].

11.3.3.5 Preliminary Design Substantiation

11.3.3.5.1 Compliance with Safety Functional Requirements

<u>Control of reactivity</u>

The VVP [MSS] does not perform the reactivity control function directly [12].

The VVP [MSS] is designed to prevent potential over-cooling or dilution of the RCP [RCS] to support the reactivity control function [12].

a) In the case of excessive increase in steam flow events, the MSLs are automatically isolated to prevent core overcooling;

b) In the case of SGTR conditions, with no reactor coolant pump in operation and with a failure of the VDA [ASDS] train of the affected SG, VVP [MSS] services are available as a route that the steam can be transferred via the warm-up line to other trains and discharged by the VDA [ASDS], thus depressurising the affected SG. In this way, the reverse flow from the affected SG to the RCP [RCS] can be minimised.

<u>Removal of heat</u>

The VVP [MSS] is designed to perform the heat removal function as identified below

[12]:

a) During plant power operation, the VVP [MSS] is designed to ensure continuous heat removal from the RCP [RCS] by steam transfer to the team turbine;

b) During plant normal shutdown, after the reactor has been switched off, the VVP [MSS] is designed to remove residual heat from the RCP [RCS] to the condenser until the RIS [SIS] is connected to the RCP [RCS] in RHR mode;

c) Under DBC or DEC-A events, the VVP [MSS] is designed to ensure the heat of RCP [RCS] can be removed.

Confinement

VVP [MSS] performs the confinement function as identified below [12]:

a) In the case of SGTR, the VVP [MSS] isolates the affected SG to prevent radioactive fluid discharging to the environment directly;

b) During SA, the VVP [MSS] participates in the isolation of containment.

Extra Supporting Function

The design of the VVP [MSS] supports the control of reactivity, removal of heat and confinement functions via providing the necessary operating parameters of the main steam, providing mechanical supporting functions and providing other supporting functions.

Moreover, the design of the VVP [MSS] acts to prevent, protect and mitigate the hazard impact of internal and external hazards.

Therefore, the VVP [MSS] performs the following extra supporting functions [12]:

a) Monitoring the ambient conditions in the VVP [MSS] valve compartment;

b) Contribution to over-pressure protection of the pressure retaining boundary via MSSVs.

Moreover, the states of components which perform important the safety functions are monitored and indicated to the operator [12].

The system design results have been estimated in the safety analysis (see Chapters 12 and 13). At the current stage, there are no further safety functional requirements derived for the VVP [MSS].

11.3.3.5.2 Compliance with Design Requirements

Safety Classification

The design principle is presented in Sub-chapter 11.2.4.

The safety classification of VVP [MSS] functions is listed in Table T-11C-5. The safety classification of main components is listed in Table T-11C-6 and in Reference [7].

The results of safety classification of the VVP [MSS] complies with the design principles.

Engineering Design Requirements

a) Single Failure Criterion (SFC)

Application of the SFC for components performing FC1 and Safety Category 2 Functions (FC2) in the VVP [MSS] is as follows:

1) In consideration of the requirement for heat removal, the VVP [MSS] is composed of three trains, each corresponding to one SG;

2) The SFC is not applied to the closure of the MSIV in the case of SGTR. During other DBC conditions (such as SLB), in the case of MSIV closing failure, the unaffected MSIVs isolate the corresponding SGs from break. Furthermore the main feedwater line of the affected SG is isolated. The actuator of the MSIV is equipped with redundant manifolds so as to prevent MSIV closing failure caused by the malfunction of either manifold;

3) The bypass line of the MSIV is equipped with an isolation valve and a control valve. During accident conditions the bypass line control valve performs the isolation function in concert with the bypass line isolation valve. The bypass line isolation valve and bypass line control are redundant for bypass line isolation;

4) The drain line of the VVP [MSS] is fitted with two redundant isolation valves in order to prevent failure of drain line isolation.

b) Independence

The VVP [MSS] consists of three trains connected to the SGs separately. The independence principle is not applied to the VVP [MSS].

However, the MSIVs are located in different rooms in order ensure the availability of safety functions.

c) Diversity

The VVP [MSS] serves as a discharging route to support the heat removal function. In this way, the principle of diversity is not applied to the VVP [MSS].

However, the overpressure protection of the secondary pressure retaining boundary is provided by the VDA and MSSVs from the diversity point of view.

d) Fail-Safe

Fail-safe design is applied to the pilots of MSIV. In case of losing one division of electrical power, the arrangement of the pilots ensure that safety functions of the MSIV can be maintained.

e) Ageing and Degradation

The main components of the VVP [MSS] is designed for the 60 year plant operation. These components mainly include:

1) MSLs;

2) MSIVs;

3) MSSVs.

The ageing factors concerning individual components will be analysis and the adequate arrangement of examination, inspection, maintenance and testing will be provided to ensure the safety functional performance [12].

f) Human Factors

The system design as well as the control function design of the VVP [MSS] does not require short term operator intervention (within 30 minutes after initial event).

Under plant accident conditions, the MSIVs are isolated automatically when receiving the protection signal from the RPS [RPS]. Under plant post-accident conditions, as there is no urgent demand to isolate the MSL as quickly as possible, the MSIVs can be isolated manually by the operator if necessary. In order to reduce the human actions, grouped control is designed for the operator.

Moreover, the operating status of the pilots of the MSIVs are monitored and indicated to the operator. An alarm will be triggered in the MCR if the valve position is left in wrong location after maintenance [12].

g) Autonomy

1) Autonomy in Respect to Operators

The design principles relevant to the autonomy in respect to operators are listed in Reference [2]. The design of the VVP [MSS] fulfils these principles via control function design [12]. The design result has been estimated in the safety analysis.

2) Autonomy in Respect to the Heat Sink

These design principles are relevant to heat sink design and are not applicable for the VVP [MSS].

3) Autonomy in Respect to Power Supply Systems

This principle is not applicable for the VVP [MSS]. However, the power supply requirements of the important components which perform safety functions are identified in Reference [7].

The MSIVs are powered by Emergency Diesel Generators (EDG), Station Black Out (SBO) diesel generators and the Uninterruptible Power Supply (UPS). The bypass line valves and drain line valves are powered by EDGs.

h) Other design requirements

1) Prevention of Harmful Interactions of Systems Important to Safety

The VVP [MSS] operates at high pressure and temperature normally. Various systems are connected to the VVP [MSS] to support the safety function or normal operational function. Provisions have been made to prevent the design pressure of the system, operating at the lower pressure, from being exceeded.

The venting lines of MSLs are physically isolated via quick coupling or a blind flange. Moreover, double isolation is preferred to be used in order to provide adequate isolation between the VVP [MSS] and interfacing systems to prevent harmful interactions [21].

2) Considerations Related to the Electrical Power Grid

As there is no pump in the VVP [MSS], the disturbances in the electrical power grid will not have an influence on the system.

Equipment Qualification

The seismic classification for the main equipment of the VVP [MSS] is presented in Table T-11C-6. More information is presented in References [7] and [18].

The documents relevant to the equipment qualification will be delivered during Step 4 of GDA. These documents are being prepared at the current stage. { }.

Protection against Internal and External hazards

Considering the protection against internal and external hazards, the design measures are presented in Reference [18]. The design measures used in system design are demonstrated below. The results of system design will be systematically analysed and presented in Chapters 18 and 19.

a) Internal hazards

1) Internal Fire

The three redundant trains of the VVP [MSS] are arranged in different buildings. Only one train will be affected in the case of internal fire at a time.

2) Internal Flooding

Only one train of the VVP [MSS] will be damaged at a time in the case of internal flooding based on the layout design.

The components of the VVP [MSS] and ARE [MFFCS] corresponding to the same SG are arranged in different compartments to minimise the potential influence of internal flooding induced by the ARE [MFFCS] on the VVP [MSS].

3) High Energy Pipe Failures

The three MSLs are strictly separated from each other. The compartments of the VVP [MSS] equipment are separated from the ARE [MFFCS] pipes to minimise the potential influence of internal flooding.

4) Dropped Loads

Precautions are applied during layout design to avoid dropped loads, such as appropriate design and management of hoisting equipment.

5) Internal Missiles

The three redundant trains of the VVP [MSS] are arranged in different buildings for segregation. The system is protected from the effect of internal missile by the layout design.

6) Internal Explosion

The system is protected from the effect of internal explosion by the layout design. Only one train will be damaged in the case of internal explosion at a time. Moreover, there is no source of explosion used in VVP [MSS].

b) External hazards

1) Earthquake

The equipment of the VVP [MSS] which perform the safety functions are required to be seismic qualified to ensure their functional ability. The requirements will be transfer to the equipment vendor in the form of a qualification specification.

Moreover, the earthquake is also resisted by the civil structure design. The information of the civil structure is presented in Chapter 16.

2) External Flooding

The layout of the VVP [MSS] is designed to be at a height that the risk of being affected by external flooding can be eliminated.

3) External Explosion

The VVP [MSS] is arranged in safety-classified structures, for which Explosion Pressure Waves (EPW) are considered during design to maintain its stability in the case of external explosion.

The majority of the VVP [MSS] safety-classified components are protected against EPW by civil structures.

4) Lightning and Electromagnetic Interference

This hazard is mainly resisted by the I&C and electrical systems design. There is no special measure used in the VVP [MSS].

5) Airplane Crash

The components of the VVP [MSS] outside the containment are arranged in three different valve stations, with two trains at the top of Safeguard Building B (BSB) and one at top of Safeguard Building A (BSA). The effects on the VVP [MSS] of an Airplane Crash (APC) will be analysed in hazard analysis (Chapter 18).

Commissioning

Initial testing (e.g. factory acceptance tests) of components before delivery to site shall be undertaken to ensure the safety functions of these components can be properly performed. The design requirements will be provided to the equipment vendor in the form of technical specifications.

After the components been delivered to the site, the following tests will be implemented to validate the operability of individual components and system functions during the commission stage based on the current design [12]:

a) Valve Test: Examination and testing of valves;

b) Measurement Test: Preliminary test, and control channel precision, set point and alarm tests on instrumentation;

c) Logic Control Channel Test: Control channel precision, set point and alarm tests on other instrumentation;

d) MSIV Test: Operability of the MSIV and its solenoid pilot valve, correct action of stem limit switch, action sequence and opening/closing time of the MSIV;

e) Warm-up Line Test: Operability, operating time and flow capacity of the warm-up line.

The documents relevant to the commissioning for the UK HPR1000 are being prepared at the current stage. {

}

Examination, Inspection, Maintenance and Testing

The VVP [MSS] design has a series of surveillance methods to monitor the system configuration status in real time so as to help the operator be aware of the system operational status at any time, to allow them to intervene during abnormal events to ensure the safe operation of the system. The main surveillance methods include:

a) VVP [MSS] operating condition surveillance;

b) The MSIVs operating condition surveillance;

c) The MSSVs operating condition surveillance;

d) VVP [MSS] valve compartment temperature surveillance.

The maintenance plan for equipment of the VVP [MSS] will be determined after receiving supplier data. During power operation, the VVP [MSS] will not be subjected to on-line maintenance. Visual inspection can be implemented on the safety-classified equipment of the VVP [MSS].

For the UK HPR1000, the periodic test design will be adapted from those developed for the HPR1000 (FCG3). The following periodic tests shall be conducted regularly:

a) Main steam isolation valve: in the hot shutdown condition, a quick-closing test for valve is conducted. It is preferable to carry out this test during the refuelling shutdown of the unit. A partial-closing test is conducted during power operation, however the core power output shall not be influenced. In the cold shutdown condition a visual inspection can be carried out;

b) MSIV pilot-operated valve: during the partial-closing test of the main valve, the control of each pilot-operated valve is tested;

c) Main steam safety valve: in the hot shutdown condition, the set point of the safety valves will be verified;

d) SG pressure measuring system: validity check and calibration test are conducted for the SG pressure sensor.

More detailed information is presented in Reference [12].

The documents relevant to the EMIT for the UK HPR1000 are being prepared. { }

Special Thermal-Hydraulic Phenomena

The applicable hydraulic phenomena are identified and presented below:

a) Phenomenon regarding water hammers

Improper arrangement of steam drain lines may lead to water hammers caused by steam pushing the water plug.

Draining lines are designed to eliminate the water hammer phenomena. This information related to this design feature is presented in detail in Reference [18].

Material Selection

All equipment and piping materials for the VVP [MSS] are carbon steel.

In normal operation, the medium transmitted by the system is not radioactive. Furthermore the VVP [MSS] equipment and pipelines are designed with adequate margin (i.e. erosion allowance) taken into consideration for pipeline wall thickness [23].

Insulation

Insulation of the VVP [MSS] is mainly considered in respect to the operator safety. Accessible equipment or pipelines with high surface temperatures are insulated to prevent burns [23].

This is applicable to all VVP [MSS] pipelines and equipment with an internal fluid temperature greater than 60°C, therefore, all the valves and pipelines of the VVP [MSS] are subject to the insulation design.

Decommissioning

The principles and methodology are presented in Chapter 24 (Decommissioning). The design of the VVP [MSS] will take these principles and methodology into account. The design result and relevant analysis will be presented in the safety case of Chapter 24.

11.3.3.6 Functional Diagrams

The simplified functional diagram is presented in Appendix 11B Figure F-11B-2. The detailed functional diagram is presented in Reference [21].

11.3.4 Main Feedwater Flow Control System

11.3.4.1 Safety Functional Requirements

11.3.4.1.1 Control of reactivity

The ARE [MFFCS] does not perform the reactivity control function directly. However, under plant normal operation or accident condition, the ARE [MFFCS] shall be designed to contribute to the reactivity control function via preventing overcooling of the RCP [RCS] by controlling and isolating the valves automatically.

11.3.4.1.2 Removal of heat

Under plant normal operation and normal transients, the ARE [MFFCS] shall be designed to ensure the heat removal function by controlling the flow rate of the feedwater automatically.

11.3.4.1.3 Confinement

Under plant accident conditions, the ARE [MFFCS] shall be designed to perform the confinement functions by isolating the feed water automatically or manually as identified below:

a) In the case of SLB or FLB in the reactor building, the ARE [MFFCS] shall contribute to limit mass and energy release to the containment via automatic isolation in order to protect the containment from over-pressure;

b) In the case of SGTR, the ARE [MFFCS] shall contribute to avoid SG overfilling via automatic isolation in order to prevent the radioactive fluid discharging to the environment directly;

c) Under the SA condition, the ARE [MFFCS] shall ensure the main feedwater line that penetrates containment has been isolated via automatic isolation. Moreover, if the electrical power is lost, the un-interrupted battery equipped to the valves ensures the isolation action can be performed manually.

11.3.4.1.4 Extra Supporting Function

The design of the ARE [MFFCS] shall support the control of reactivity, removal of heat and confinement functions via providing necessary system information, providing mechanical supporting functions and providing other supporting functions.

Moreover, the design of the ARE [MFFCS] shall prevent, protect and mitigate hazard impact of internal and external hazards.

To achieve the extra supporting functions, the ARE [MFFCS] design should ensure that important system operation parameters as well as the status information relevant to the components which perform the safety functions is to be monitored and indicated to the operator.

11.3.4.2 Design Requirements

The engineering design requirements are integrated and introduced in Sub-chapter 11.2.4. Each engineering design requirement is analysed and the applicable items are identified for the ARE [MFFCS]. The detailed information is presented in Reference [8] and [23].

The following principles are not applicable for the ARE [MFFCS]:

a) Autonomy in Respect to the Heat Sink

The ARE [MFFCS] is not a heat sink system. Therefore this principle is not applicable for the ARE [MFFCS].

b) Autonomy in Respect to Power Supply Systems

This principle is mainly used in the power supply systems design and is not applicable for the ARE [MFFCS].

c) Considerations Related to the Electrical Power Grid

The ARE [MFFCS] does not include pumps and other equipment affected by the power grid.

11.3.4.3 Design Bases

The general assumptions are mainly derived from design requirements presented in Sub-chapter 11.3.4.2. The applicable principles which may affect the equipment sizing and the relevant assumptions are demonstrated in Sub-chapter 11.3.4.3.1.

The design assumptions are mainly derived from safety functional requirements presented in Sub-chapter 11.3.4.1. These assumptions are demonstrated in Sub-chapter 11.3.4.3.2.

11.3.4.3.1 General Assumption

<u>Safety Classification</u>

The main feedwater isolation function is used to achieve the safe condition under DBC2-4 conditions. Therefore, the function classification is FC1.

SG and containment isolation is used to achieve the safe condition under DBC2-4 conditions. Therefore, the functions' classifications are FC1.

The SG water level control function is used to maintain the operating parameters within operating limits in order to prevent initiation of the engineered safety systems. Therefore, the functions' classification is FC3.

The safety classification of the VVP [MSS] functions is listed in Table T-11C-5 and Reference [7].

<u>Ageing and Degradation</u>

According to Chapter 2, the operational design life of the UK HPR1000 is 60 years. The main components of the ARE [MFFCS] is designed for the 60 year plant operation.

During system and equipment design, the ageing and degradation of the equipment which are important to safety must be taken into account.

Moreover, the ageing effects of sensors such as drift shall be considered. This is applied in monitoring control function design.

<u>Equipment Qualification</u>

Active components of the ARE [MFFCS] that perform FC1 or FC2 safety functions shall be qualified. Active components of the ARE [MFFCS] that perform FC3 safety functions required under DEC conditions shall be qualified.

Hazards

These hazards may induce an environmental condition change in the compartment where the equipment is located. Moreover, safety functions such as the confinement function shall be performed under earthquake events. Therefore, the equipment design shall take the effects of hazards into account to ensure the ability of the safety function.

11.3.4.3.2 Design Assumption

Control of Reactivity

In normal power operation, the ARE [MFFCS] contributes to limit the overcooling of the RCP [RCS] by controlling the water level in SGs to the designed level and variation as specified below:

a) Full Load Control Valves (FLCVs)

   Regulate the feedwater flow at about 20%-100% rated power.

b) Low Load Control Valves (LLCVs)

   Regulate the feedwater flow from the hot standby stage to around 20% nominal power.

c) Very Low Load Control Valves (VLLCVs)

   Regulate the feedwater flow during plant startup or shutdown.

In accident conditions (DBC2-4 and DEC-A), the ARE [MFFCS] contributes to the control of reactivity via limiting the overcooling of the RCP [RCS]. This function is performed by rapid isolation of the feedwater to the SG. The requirements of the closing time of the isolation valves are:

a) Full Load Line Isolation Valves (FLIVs): no more than 5 seconds;

b) Low Load Isolation Valves (LLIVs): no more than 20 seconds.

Removal of heat

The ARE [MFFCS] maintains the SG level at the design limits to ensure removal of heat during steady operation and normal transients by controlling the feedwater to be at the required flow rates. The requirements for the FLCVs, LLCVs and VLLCVs are the same as mentioned above.

Confinement

In the case of SLB or FLB in the reactor building, the ARE [MFFCS] isolates the feedwater line to limit mass and energy release to the containment to prevent containment over-pressurisation.

In the case of SGTR, the ARE [MFFCS] performs SG isolation and main feedwater isolation to avoid SG overfilling, and prevent the radioactive fluid from releasing to the environment.

Under a SA, the ARE [MFFCS] ensures containment isolation of the main feedwater line that penetrates containment to prevent a significant amount of radioactive substances from escaping to the environment.

The requirement of the Main Isolation Valves (MIVs) closing time is for it to be no more than 240 seconds.

Extra Supporting Function

Important system operation parameters which indicate the safety operation status of the ARE [MFFCS] shall be monitored as indicated below:

a) Flow rate of main feedwater;

b) Temperature of main feedwater;

c) SG water level;

d) Ambient temperature of the ARE [MFFCS] valve compartment.

The status of valves which are used to perform the safety functions shall be monitored. This includes the FLCVs, LLCVs, VLLCVs as well as the isolation valves.

11.3.4.4 System Description and Operation

11.3.4.4.1 System Configuration

This system consists of the pipes and valves that transfer feedwater from a common feedwater header to three SGs; to remove the heat produced by the reactor core during normal operation as well as the residual heat in the initial phase of shutdown operation before the RIS [SIS] connects to the RCP [RCS] [24].

Each main feedwater line contains:

a) Feed water flow rate control valves;

b) Feed water isolation valves.

FLIVs and LLIVs are all located in the valve compartment in the safeguard building. The FLCVs, LLCVs and VLLCVs are connected via parallel lines. These control valves are to maintain the water level in the associated SG at the required value.

Two FLIVs are installed upstream and downstream of each FLCV to isolate the full load line and SGs to limit feed water leakage into the containment. Similarly, two LLIVs are installed upstream and downstream of each LLCV to isolate the low load line and SGs to stop feed water leaking into the containment.

There is a check valve close to the SG inside the containment for each main feed line to prevent reverse flow and uncontrolled discharge from the SG in the event of FLB.

11.3.4.4.2 Main Equipment

Flow Rate Control Valves

Three control valves are mounted on each feedwater line to control the flow rate based on the different thermal power levels of the plant:

a) FLCV controls the feed water flow rate to the SG from 20% to 100% nominal thermal power;

b) LLCV controls the feed water flow rate to the SG from 2% to 20% nominal power;

c) VLLCV controls the feed water flow rate to the SG from plant shutdown to around 2% nominal power.

These control valves are pneumatic valves made of carbon steel, which are designed and manufactured according to RCC-M.

Full Load Line Isolation Valve

The FLIV is used to isolate the full load feedwater line under DBC condition.

The FLIV is a wedge gate valve and fitted with an oleo-pneumatic actuator. The valves are designed and manufactured according to the RCC-M code. The general parameters of the FLIV are shown in Table T-11C-7.

The actuator consists of a piston, a chamber filled with compressed nitrogen and a hydraulic fluid loop. The hydraulic fluid loop contains two redundant drainage manifolds which are connected on the lower chamber. One of the manifolds is connected with an oil pump which pumps oil into the lower chamber to move the piston and open the valve.

Main Isolation Valve

The MIV isolates the main feedwater line route to the SG and performs the containment isolating function. The MIV is arranged outside of the BRX and located as close as possible to the containment penetration.

The MIV is a wedge gate valve and is fitted with an electrical actuator. The valves are designed and manufactured according to RCC-M.

For the main equipment mentioned above, detailed information relevant to the component design such as the design parameters is presented in Reference [24].

11.3.4.4.3 Main Layout

The following factors needs to be considered during system layout design of the

ARE [MFFCS], such as external and internal hazard protection, radiological protection, layout requirements for equipment, piping, special thermal-hydraulic phenomena as well as examination, maintenance and replacement, special system consideration, operating experience, etc.

The other main components of the ARE [MFFCS] are located in the safeguard building in such a way that the three main feedwater lines are separated from each other physical.

The arrangement of the ARE [MFFCS] components and pipes considers the installation, maintenance, replacement and protection against internal hazards.

More detailed information of ARE [MFFCS] layout design is presented in Reference [23].

11.3.4.4.4 System Interface

The main supporting systems of the ARE [MFFCS] are as indicated below:

a) AAD [SSFS];

b) AHP [HPFHS];

c) APA [MFPS];

d) Instrument Compressed Air Distribution System (SAR [ICADS]).

The main user systems of the ARE [MFFCS] are as indicated below:

a) RCP [RCS];

b) ADG [FDTGSS].

More detailed information of the interfacing systems and the functional requirements is presented in Reference [24].

11.3.4.4.5 System Instrumentation and Control

Automatic control

During normal operation, control valves of the ARE [MFFCS] regulate the flow rate of feedwater automatically based on the SG level.

Under accident conditions, isolation valves of the ARE [MFFCS] close automatically when receiving the isolation signal from the RPS [RPS].

Information to the Operator

The information available to the operator in the MCR for each ARE [MFFCS] train is as follows:

a) The water level of SG;

b) The analogical positions of control valves;

c) The position of isolation valves;

d) The feedwater flow rate;

e) The feedwater temperature;

f) The FLIV actuator position.

More detailed information of the ARE [MFFCS] control function design is provided in Reference [13].

11.3.4.4.6 System Operation

Plant Normal Condition

During 100% nominal power operation of the plant, the operating parameters of the feedwater for each SG are as indicated below:

a) Feedwater temperature: 228ºC;

b) Feedwater flowrate: 592.81kg/s.

Between 20% to 100% of nominal power, the water level of the SG is controlled by FLCVs and the feedwater is supplied by the APA [MFPS].

Between 2% to about 20% of nominal power, the water level of the SG is controlled by the LLCVs and the feedwater is supplied by the AAD [SSFS].

Between 0% to about 2% of nominal power, the water level of the SG is controlled by the VLLCVs, and the feedwater can be supplied either by the APA [MFPS] or by the AAD [SSFS].

After the RIS [SIS] connects to the RCP [RCS], the operator isolates the ARE [MFFCS] manually according to the operation conditions of the primary circuit.

More detailed information of the operation of the ARE [MFFCS] is presented in Reference [13].

Plant Fault or Accident Condition

Under accident conditions, the main feedwater will be isolated by closing the FLIVs, LLIVs and MIVs so that the safety related functions which involve the ARE [MFFCS] can be realised.

More information relevant to system operation under plant accident as well as system failure or malfunction is presented in Reference [12].

11.3.4.5 Preliminary Design Substantiation

11.3.4.5.1 Compliance with Safety Functional Requirements

Control of Reactivity

During plant normal operation, the ARE [MFFCS] contributes to limit the overcooling of the RCP [RCS] by controlling the water level in SGs to the designed level and variation.

Under DBC2-4 and DEC-A conditions, the ARE [MFFCS] contributes to the control of reactivity via limiting the overcooling of the RCP [RCS] [13].

Removal of Heat

The ARE [MFFCS] maintains the SG level to the design limits to ensure removal of heat during steady operation and normal transients by controlling the feedwater to be at the required flow rates [13].

Confinement

In the case of SLB or FLB in the reactor building, the ARE [MFFCS] isolates the feedwater line to limit mass and energy release to the containment to prevent containment over-pressurisation [13].

In the case of SGTR, the ARE [MFFCS] performs SG isolation and main feedwater isolation to avoid SG overfilling, and prevent the radioactive fluid from releasing to the environment [13].

Under SA, the ARE [MFFCS] ensures containment isolation of the main feedwater line that penetrates containment to prevent a significant amount of radioactive substances from escaping to the environment [13].

Extra Supporting Functions

Important system operation parameters which indicate the safety operation status of the ARE [MFFCS] will be monitored as indicated below [13]:

a) Flow rate of main feedwater;

b) Temperature of main feedwater;

c) SG water level;

d) Ambient temperature of the ARE [MFFCS] valve compartment.

Important status information of components which are used to perform the safety functions shall be monitored [13], [25].

11.3.4.5.2 Compliance with Design Requirements

Safety Classification

The ARE [MFFCS] design is compliant with the requirements described in the Chapter 4. The safety classification of the ARE [MFFCS] functions is listed in Reference [8] and in Table T-11C-8 and the safety classification of main components in Reference [8] and in Table T-11C-9.

Engineering Design Requirement

a) Codes and Standards

This is described in Sub-chapter 11.3.1.

b) Single Failure Criterion (SFC)

To meet the SFC, the full load pipeline is equipped with two FLIVs in series while the low load pipeline is equipped with two LLIVs. The isolation valves are equipped with emergency power supplies and are fed by different power supply divisions. In addition, the check valve inside the reactor building and the MIV can ensure single failure criterion for the containment isolation.

c) Independence

The VVP [MSS] consists of three trains. Each train is located in a safeguard building respectively.

d) Diversity

The isolation of containment is performed by the MIV and the check-valve. This design configuration complies with the requirement of diversity.

e) Fail-Safe

Fail-safe design is applied to the pilots of the FLIV. In case of losing nitrogen supply, the arrangement of the pilots ensures that the safety functions of the FLIV can be maintained.

f) Ageing and Degradation

According to Chapter 2, the operational design life of the UK HPR1000 is 60 years. The main components of the ARE [MFFCS] are designed for the 60 year plant operation.

The ageing factors concerning individual components will be analysis and the adequate arrangement of examination, inspection, maintenance and testing will be provided to ensure the safety functional performance [13].

g) Human Factors

The system design as well as the control function design of the ARE [MFFCS] does not require short term operator intervention (within 30 minutes after initial event).

During plant normal operation, the flowrate of feedwater is designed as being automatically control. Under accident conditions, the feedwater lines are isolated automatically. Detailed information related to the system control functions is presented in Reference [13].

h) Autonomy

1) Autonomy in Respect to Operators

The design principles relevant to the autonomy in respect to operators are listed in Reference [2]. The ARE [MFFCS] fulfils these principles via control function design [13]. The design results are estimated in the safety analysis.

2) Autonomy in Respect to the Heat Sink

The design principles relevant to the autonomy in respect to the heat sink are not applicable for ARE [MFFCS] design.

3) Autonomy in Respect to Power Supply Systems

These principles are mainly relevant to the electrical power supply systems design and are not applicable for the ARE [MFFCS].

The power supply requirements of the important components which perform safety functions are identified in Reference [8]. The FLIVs are powered by EDGs and the UPS. The LLIVs are powered by EDGs. The MIVs are powered by EDGs and the UPS.

i) Other design requirements

1) Prevention of Harmful Interactions of Systems Important to Safety

The ARE [MFFCS] normally operates at high pressure and temperature. Various systems are connected to the ARE [MFFCS] to support the safety function or normal operational function. Provisions have been made to prevent the design pressure of the system operating at the lower pressure from being exceeded. This is mainly achieved by the design measures stated below:

- Provide adequate isolation (e.g. using double isolating valves) between the ARE [MFFCS] and interfacing systems [25];
- Appropriate control function design to protect the interfacing system from overpressure via automatic isolation [13].

2) Considerations Related to the Electrical Power Grid

The functional reliability of the main valves shall be substantiated by the equipment vendor, taking the electrical power grid fluctuations into account.

Equipment Qualification

The seismic classification for the main equipment of the ARE [MFFCS] is presented in Table T-11C-9. More information is presented in Reference [8] and [23].

The documents relevant to the equipment qualification will be delivered during step 4 of GDA. These documents are being prepared at the current stage. { }

Protection against Internal and External hazards

a) Internal Hazards

1) Internal fire

In case of fire within the containment, the equipment of the ARE [MFFCS] is protected from damage by the layout design (divisions as well as protection against internal missiles);

In case of fire within the safeguard building, the redundant components which perform the same safety function are separated by walls.

2) Internal flooding

In the reactor building, the equipment of the ARE [MFFCS] involved in the safety functions will be installed at a level high enough to avoid damage due to flooding.

In the feedwater valve compartment outside the reactor building, the equipment of the ARE [MFFCS] involved in the safety functions will be installed such a large enough height as to prevent it from being damaged by flooding.

3) High energy pipe failures

Within the reactor building, the layout design can prevent the feedwater pipes of the ARE [MFFCS] from the dynamic effects caused by the breakage of a high energy pipe of another system.

Outside the reactor building, the pipes and valves of the ARE [MFFCS] within the valve compartments are protected by structures against the effects of the breakage of a high energy pipe of another system, especially the breakage of a main steam pipe.

In the feedwater valve compartment，the layout design (for the independent compartment of each train of the feedwater pipe) ensures that the breakage of a main feedwater pipe will not have any impact on other feedwater pipes and any of the main steam pipes.

4) Dropped loads

Precautions are applied during the layout design to avoid dropped loads, such as appropriate design and management of the hoisting equipment.

5) Internal missiles

The layout and structural design ensures that there is no risk of damage to the ARE [MFFCS] pipes due to potential internal missiles.

The layout and structural design ensures that there is no risk of damage to the safety-classified components of the ARE [MFFCS] due to the missiles from the main steam pipes or other main feedwater pipes.

6) Internal explosion

There is no flammable fluid contained in ARE [MFFCS].

b) External Hazards [23]

1) Earthquake

The equipment of the ARE [MFFCS] which perform the safety functions are required to be seismic qualified to ensure the functional ability. The requirements will be specified to the equipment vendor in the form of qualification specifications.

2) External flooding

The part of the ARE [MFFCS] outside the containment is set at the top of the safeguard buildings, to ensure the ARE [MFFCS] can be protected from external flooding.

3) External explosion

The BRX and safeguard building are designed to withstand the effects of a shock wave due to external explosions.

In the BRX and feedwater valve compartments, the safety-classified components of the ARE [MFFCS] can resist the explosive shock wave by means of the civil structure.

4) Lightning and electromagnetic interference

This hazard is mainly resisted by I&C and electrical systems design. There is no special measure used in the ARE [MFFCS].

5) Airplane crash

The components of the ARE [MFFCS] located in the reactor building are protected from the effect of an APC by the civil structure.

The components of the ARE [MFFCS] outside the containment are arranged in three different valve stations, with two trains at top of safeguard Building B (BSB) and one at top of Safeguard Building A (BSA). The effects of the APC on the ARE [MFFCS] will be analysed in chapter 18.

Commissioning

Initial testing (e.g. factory acceptance tests) of components before delivery to site shall be undertaken to ensure the safety functions of these components can be properly performed. The design requirements will be provided to the equipment vendor in the form of technical specifications.

After the components have been delivered to the site, the following tests will be implemented to validate the operability of individual components and system functions during the commission stage based on the current design [13]:

a) FLIV Test: Operability of the FLIV, correct action of stem limit switch, action sequence and closing time;

b) LLIV and MIV Test: Operability of the LLIV and MIV, action sequence and closing time;

c) FLCV, LLCV and VLLCV Test: Operability, correct action of stem limit switch, operating time and correct valve position;

d) Valve Test: Examination and test on other valves;

e) Measurement Test: Preliminary test, and control channel precision, set point and alarm test on the instrumentation;

f) Logic Control Channel Test: Control channel precision, set point and alarm test on other instrumentation.

The documents relevant to the commissioning for the UK HPR1000 are being prepared. { }

Examination, Inspection, Maintenance and Testing

The ARE [MFFCS] contains a number of means of monitoring important system operation parameters and status information of components. The monitoring can indicate to the operators current operational information of system and components and allow them take appropriate actions in the case of abnormal events [13].

The monitoring means of the ARE [MFFCS] are as follows:

a) Flow rate of main feedwater;

b) Temperature of main feedwater;

c) SG water level;

d) Ambient temperature of the ARE [MFFCS] valve compartment;

e) Pressure drop of the VLLCV.

The maintenance plan for equipment of the ARE [MFFCS] will be determined after obtaining supplier data. There is no requirement for the preventative maintenance during operation at power of ARE [MFFCS] classified equipment and visual inspections can be implemented on it [13].

Personnel shall be kept away from radioactive environments as much as possible through the following measures:

a) The number of welding operations during in-service inspections shall be maintained as low as practicable;

b) External in-service inspections are preferred .

In-service inspections on ARE [MFFCS] components within containment shall be implemented during the shutdown state (inspection is not required at operation at power).

Periodic tests can be applied to ensure the availability of equipment and that the characteristic data remains correct. Periodic tests of ARE [MFFCS] valves shall be considered as permitted during the design process [13].

The ARE [MFFCS] periodic tests are indicated below:

a) Operability of ARE [MFFCS] FLIVs;

b) Operability of ARE [MFFCS] LLIVs;

c) Operability of MIV.

More information related to the EMIT of the ARE [MFFCS] is presented in Reference [13].

The documents relevant to the EMIT for the UK HPR1000 are being prepared. { }

<u>Special Thermal-Hydraulic Phenomena</u>

These applicable hydraulic phenomena are identified and presented below:

a) Phenomenon regarding the thermal stratification

This is considered in the interfacing of SG design. The feedwater interfaces of SGs for the Emergency Feedwater System (ASG [EFWS]) and ARE [MFFCS] are independent. Under accident conditions, when the ARE [MFFCS] is isolated and ASG [EFWS] is in startup, this helps to avoid thermal stratification in the ARE [MFFCS] feedwater line due to the low temperature water injection into SGs of the ASG [EFWS].

b) Phenomenon regarding the water hammers

Water hammer is considered in the check valves design of the ARE [MFFCS]. The check valves are set close to the SGs as much as possible to perform the isolation function after the ARE [MFFCS] is tripped under accident conditions in order to prevent the degradation of the water inventory in the SG secondary side. The fast closing time of check valve is a potential source of water hammer. Therefore, the closing times of these check valves are carefully analysed and selected. The requirements of the closing times for these valves presented to the equipment vendor in the form of a technical specification.

More information related to the special thermal-hydraulic phenomena considered in ARE [MFFCS] design is presented in Reference [23].

Material Selection

All of the components and pipes of the ARE [MFFCS] are made from carbon steel.

The content of Cr in the materials of ARE [MFFCS] components is controlled, so that they can have adequate resistance to flow accelerated corrosion [8].

Insulation

Insulation of the ARE [MFFCS] is mainly considered in respect to the safety of operator. Accessible equipment or pipelines with a high surface temperature are insulated to prevent burns [23].

This is applicable to all ARE [MFFCS] pipelines and equipment with a fluid temperature greater than 60°C, therefore, all the valves and pipelines of the ARE [MFFCS] are subject to the insulation design.

Decommissioning

The principles and methodology are presented in Chapter 24 (Decommissioning). The design of the ARE [MFFCS] will take these principles and methodology into account. The design result and relevant analysis will be presented in the safety case of Chapter 24.

11.3.4.6 Functional Diagram

The simplified functional diagram is presented in Appendix 11B Figure F-11B-3. The detailed functional diagram is presented in Reference [25].

11.3.5 Steam Generator Blowdown System

11.3.5.1 Safety Functional Requirements

11.3.5.1.1 Control of Reactivity

The APG [SGBS] is not required to perform the reactivity control function directly

[11].

11.3.5.1.2 Removal of Heat

The APG [SGBS] is not required to perform heat removal function directly.

Under DBC conditions after the ASG [EFWS] is started, the blowdown of the APG [SGBS] must be isolated in order to prevent the degradation of the water inventory in the SG secondary side due to the blowdown operation [11].

11.3.5.1.3 Confinement

The APG [SGBS] shall be design to perform the confinement functions as indicated below [11]:

a) Under SGTR accident conditions, the blowdown of the affected SG must be isolated to ensure the confinement function;

b) Moreover, under SGTR accident conditions, the APG [SGBS] shall perform the water transferring function between the affected SG and other SGs to prevent overfilling of the affected SG, thus ensuring the confinement function.

11.3.5.1.4 Extra Supporting Function

The APG [SGBS] shall be designed to perform the extra supporting functions as indicated below:

a) APG [SGBS] shall monitor necessary operating information important to the safety of the operator;

b) APG [SGBS] shall protect its pipeline from overpressure to perform the hazard prevention function.

11.3.5.2 Design Requirements

The engineering design requirements are integrated and introduced in Sub-chapter 11.2.4. Each engineering design requirement is analysed and the applicable items are identified for the APG [SGBS]. The detailed information is presented in Reference [11] and [26].

The following principles are not applicable for the APG [SGBS]:

a) Diversity

There is no diversity functional requirement derived for the APG [SGBS]. Therefore this principle is not applicable for the APG [SGBS].

b) Fail-Safe

There is no fail safe design applied to the APG [SGBS]. This principle is not applicable to the APG [SGBS].

c) Autonomy in Respect to the Heat Sink

APG [SGBS] is not a heat sink system. Therefore this principle is not applicable for APG [SGBS].

d) Autonomy in Respect to Power Supply Systems

This principle is mainly used in the power supply systems design and is not applicable for the APG [SGBS].

e) Considerations Related to the Electrical Power Grid

The APG [SGBS] does not include pumps or other equipment which is affected by the power grid.

11.3.5.3 Design Bases

The general assumptions are mainly derived from design requirements presented in Sub-chapter 11.3.5.2. The applicable principles which may affect the equipment sizing and the relevant assumptions are demonstrated in Sub-chapter 11.3.5.3.1.

The design assumptions are mainly derived from the safety functional requirements presented in Sub-chapter 11.3.5.1. These assumptions are demonstrated in Sub-chapter 11.3.5.3.2.

11.3.5.3.1 General Assumption

<u>Safety Classification</u>

The SG blowdown and containment isolation function is used to achieve the safe condition under DBC2-4 conditions. Therefore, the function classification is FC1.

The safety function of water transfer between SGs is used to achieve the safe condition under DBC2-4 conditions. Therefore, the functions' classifications are FC1.

The isolation function of secondary water sampling is used to achieve the safe condition under DBC2-4 conditions. Therefore, the functions' classification is FC2.

The classification of APG [SBGS] safety functions is listed in Table T-11C-10 and Reference [7].

<u>Ageing and Degradation</u>

According to Chapter 2, the operational design life of the UK HPR1000 is 60 years. The main components of the APG [SGBS] are designed for the 60 year plant operation.

During system and equipment design, the ageing and degradation of the equipment which are important to safety must be taken into account.

Moreover, the ageing effects of sensors such as drift shall be considered. This is applied in monitoring control function design.

Equipment Qualification

Active components of the APG [SGBS] that perform FC1 or FC2 safety functions shall be qualified.

Hazards

These hazards may induce an environmental condition change in the compartment where the equipment is located. Moreover, safety functions such as the confinement function shall be performed under earthquake events. Therefore, the equipment design shall take the effects of hazards into account to ensure the ability of the safety function.

11.3.5.3.2 Design Assumption

Control of Reactivity

The APG [SGBS] is not required to perform the reactivity control function [11].

Removal of Heat

After the ASG [EFWS] has started to supply makeup to the SG to remove the core heat, the blowdown isolation valves must be closed to isolate the blowdown pipeline [11]. There is no quantitative safety related design assumption related to the closing time of the valves.

Confinement

Under SGTR accident conditions, the blowdown line of the APG [SGBS] shall be isolated automatically based on the low water level signal of the SGs. The control function design is presented in the Reference [14]. There is no quantitative safety related design assumption related to the closing time of the valves.

Under SGTR accident conditions, the water transfer function between the affected SG and other SGs is based on the water level of the affected SG combined with the reactor coolant temperature of the RCP [RCS]. Detailed information is presented in Reference [11]. There is no quantitative safety related design assumption related to the water transferring flowrate for the APG [SGBS].

Extra Supporting Functions

The position of the transfer pipeline control valves and blowdown isolation valves are monitored to support their functions under accident conditions [11].

Safety valves are set on the cooling water pipeline and downstream of the pressure and flowrate control station to protect the APG [SGBS] pipeline from overpressure.

11.3.5.4 System Description and Operation

11.3.5.4.1 System Configuration

The APG [SGBS] can be divided into various functional parts [27]:

a) Blowdown Collection

In the BRX, each SG is equipped with blowdown collection lines made up of two nozzles. Each pipe has a connection to the Nuclear Sampling System (REN [NSS]) branch and a branch to the Nitrogen Distribution System (SGN [NDS]).

Transfer lines linking the three SGs are provided to transfer the water of the affected SG towards unaffected SGs in the event of SGTR to avoid the release of contaminated liquid to the environment.

The blowdown line is equipped with two motor-operated blowdown isolation valves outside the containment which fulfil the redundancy principle.

b) Blowdown Cooling and Pressure Reducing

The three blowdown lines are connected by a header which conveys the fluid towards a regenerative heat exchanger cooled by the Condensate Extraction System (CEX [CES]).

The pressure reducing valve downstream the heat exchanger controls the blowdown water flow and pressure within the allowable range.

c) Blowdown Treatment

After cooling and pressure reducing, the cooled blowdown condensate is treated in the SG blowdown demineralising section. The blowdown condensate will be purified of corrosion products and ionic impurities.

d) Discharge Line

The demineralised water resulting from the treatment flows in a single line back to the water/steam cycle via the condenser. The blowdown condensate will be discharged into Conventional Island Liquid Waste Discharge System (SEL [LWDS (CI)]) if it cannot be discharge into the condenser or the water quality of samples for analysis has not been qualified.

11.3.5.4.2 Main Equipment

The main equipment of the APG [SGBS] is as follows [27]:

a) Blowdown Isolation Valve

The blowdown isolation valves are gate valves made of carbon steel. They perform the blowdown isolation function. The first blowdown isolation valve also performs the containment isolation function.

b) Transfer Pipeline Control Valve

The transfer pipeline control valves are globe valves made of carbon steel. They are closed under normal conditions. Under SGTR conditions, they are opened to allow water transfer between SGs.

c) Regenerative Heat exchanger

The regenerative heat exchanger of the APG [SGBS] is used to cool down the blowdown water. It is a U-shaped shell and tube heat exchanger. The tube side where blowdown water flows is made of stainless steel, while the shell side where cooling water flows is made of carbon steel.

d) Filters

The filters are installed upstream of the demineralisers and they perform mechanical filtration of the blowdown water. They are made of stainless steel.

e) Cationic Demineraliser

The cationic demineralisers are installed downstream of the filters and upstream of the anionic demineralisers. They are used to exchange cations in the blowdown water with H^+ in the resin and are made of stainless steel.

f) Anionic Demineraliser

The anionic demineralisers are installed downstream of the cationic demineralisers. They are used to exchange anions in the blowdown water with OH- in the resin and are made of stainless steel.

g) Resin Trap Filters

The resin trap filters are installed downstream of the anionic demineralisers. They are used to eliminate fragments of resin produced by the upstream demineralisers.

11.3.5.4.3 Main Layout

The following factors needs to be considered during system layout design of the APG [SGBS], such as external and internal hazard protection, radiological protection, layout requirements for equipment, piping, special thermal-hydraulic phenomenon as well as examination, maintenance and replacement, special system consideration, operating experience, etc.

Except for the parts of the pipes which are located between the taps on the steam generators and the containment, the entire system is located outside the BRX.

The blowdown isolation valves are located inside the safeguard building. The heat exchanger is located inside the Fuel Building (BFX). The cartridge filters, demineralisers and resin traps are located inside the Nuclear Auxiliary Building (BNX).

More detailed information related to the APG [SBGS] layout design is presented in Reference [26].

11.3.5.4.4 System Interface

The main supporting systems of the APG [SGBS] are as indicated below:

a) CEX [CES];

b) SGN [NDS);

c) Nuclear Island Vent and Drain System (RPE [VDS]);

d) TES [SWTS];

e) SEL [LWDS (CI)].

The main user systems of the APG [SGBS] are as indicated below:

a) RCP [RCS];

b) ADG [FDTGSS];

c) REN [NSS].

More detailed information of the interfacing systems and the functional requirements is presented in Reference [27].

11.3.5.4.5 System Instrumentation and Control

<u>Automatic control</u>

During plant normal operation, the blowdown flowrate is regulated automatically to the nominal flowrate by the blowdown flowrate control valve of the APG [SGBS].

Under accident conditions, the blowdown isolation valves close automatically at the isolation signal from the RPS [RPS].

<u>Information to the Operator</u>

The information available to the operator is as follows:

a) The flowrate of SG blowdown;

b) The water temperature of heat exchanger outlet;

c) The water flowrate of heat exchanger

d) The status of the important components which perform safety functions.

More detailed information related to the APG [SGBS] instrumentation and control is presented in Reference [14].

11.3.5.4.6 System Operation

Plant Normal Condition

During normal power operation, the SG blowdown water is removed continuously at a state flow rate and the treated blowdown water can recirculate to the condenser [14].

During plant normal start-up, the cooling water of the regenerative heat exchanger must be flowing before the blowdown starts. The CEX [CES], ADG [FDTGSS] and REN [NSS] must be ready before the APG [SGBS] starts up, the pressure and level in the SGs shall be in a certain range and one main condensate pump shall be in operation as well. The SG blowdown isolation valves and the valve downstream of regenerative heat exchanger shall be opened gradually, and the pressure reducing valve is opened to provide the required blowdown flow rate [14].

During plant normal shutdown, the APG [SGBS] can be shut down in a short time. The allowable shutdown time depends on the condenser leaks, the leakage from the primary side to the secondary side of the SG and the secondary water chemistry conditions of the SG. To shut down the APG [SGBS], the pressure reducing valve shall be closed before the isolation valve downstream of the regenerative heat exchanger is closed. The SG blowdown isolation valves outside the containment shall also be closed if necessary [14].

During cold shutdown for refuelling or maintenance, the SG can be partially or completely drained by gravity through the blowdown line. The water drained in this way is sent to the SEL [LWDS (CI)] or RPE [VDS] [14].

Plant Fault or Accident Condition

a) SG blowdown isolation after ASG [EFWS] actuation

The SG blowdown isolation valves are closed in ASG [EFWS] start-up to prevent loss of emergency feedwater.

b) SG blowdown isolation after activation of the containment isolation signal

The first SG blowdown isolation valves outside the containment shall be closed at the first stage signal of containment isolation.

c) Detection of radioactivity in blowdown water

The radioactive characteristics and chemistry of SG blowdown flows are detected by the REN [NSS]. If radioactivity is detected in the sample of the SG, the affected SG will be isolated.

d) Transfer of SG water in the event of SGTR

The transfer line transfers water from the affected SG to the unaffected SG to avoid liquid discharge resulting from a rise in the water level of the affected SG by an SGTR.

More detailed information related to the APG [SGBS] operation under plant accident as well as system failure or malfunction is presented in Reference [14].

11.3.5.5 Preliminary Design Substantiation

11.3.5.5.1 Compliance with Safety Functional Requirements

Control of Reactivity

The APG [SGBS] is not required to perform the reactivity control function.

Removal of Heat

The APG [SGBS] is not required to perform the heat removal function directly.

However, in DBC-2/3/4，the SG blowdown isolation valves of the affected SG are designed so that they can be automatically closed in case the ASG [EFWS] is started [14].

Confinement

Under SGTR accident conditions, the blowdown of the affected SG is designed to be automatically isolated to ensure the confinement of radioactive substances [14].

Under SGTR accident conditions, the water transfer function is designed so that it can be performed by the operator manually in the MCR as there is no urgent time limit (less than 30 minutes) for this safety function [14].

Extra Supporting Function

The important operating parameters as well as the status of the components which are important to the safety functions are monitored and indicated to the operator. The detailed information is presented in the Reference [14].

Safety valves are set for the APG [SGBS] to protect the system and interfacing system from overpressure, thus to preventing potential internal hazards [28].

11.3.5.5.2 Compliance with Design requirements

Safety Classification

The APG [SGBS] design is compliant with the engineering principles described in the Chapter 4. The classification of APG [SGBS] safety functions is listed in [11] and in Table T-11C-10 and the safety classification of main components is listed in [11] and in Table T-11C-11.

Engineering Design Requirement

a) Single Failure Criterion (SFC)

The APG [SGBS] active components performing safety function are subject to the single failure criterion [11]. These functions are:

1) Blowdown isolation of the SGs;

2) Water transfer between two SGs.

b) Independence

APG [SBGS] consists of three trains connected to the SGs separately.

c) Diversity

The principle is not applicable for the APG [SGBS].

d) Fail-Safe

The principle is not applicable for the APG [SGBS].

e) Ageing and Degradation

The main components of the APG [SGBS] are designed for the 60 year plant operation.

The ageing factors concerning individual components will be analysed and an adequate arrangement of examination, inspection, maintenance and testing will be provided to ensure the safety functional performance [14].

f) Human Factors

The system design as well as the control function design of the APG [SGBS] does not require short term operator intervention (within 30 minutes after the initial event) [14].

During plant normal operation, the blowdown flowrate of SGs is automatic adjusted by the APG [SGBS]. Under SGTR accident conditions, the blowdown lines of the APG [SGBS] are isolated automatically. Therefore, the demand on human actions and the risk of human error are reduced.

g) Autonomy

1) Autonomy in Respect to Operators

The design principles relevant to the autonomy in respect to operators are listed in [2]. The design of the APG [SGBS] fulfils these principles via control function design [14]. The design result has been estimated in the safety analysis.

2) Autonomy in Respect to the Heat Sink

The principle is not applicable for the APG [SGBS].

3) Autonomy in Respect of Power Supply Systems

The principle is not applicable for the APG [SGBS].

However, the power supply requirements of the important components which perform safety functions are identified in [11]. The blowdown isolation valves are powered by EDGs and the UPS. The transfer line valves are powered by EDGs.

h) Other design requirements

1) Prevention of Harmful Interactions of Systems Important to Safety

Provisions are made to prevent the design pressure of the interfacing system operating at the lower pressure from being exceeded. This is mainly achieved by the design measures stated below:

- Provide adequate isolation (e.g. using double isolating valves) between the APG [SGBS] and interfacing systems [28];
- Appropriate control function design to protect the interfacing system from overpressure via automatic isolation [14].

2) Considerations Related to the Electrical Power Grid

The principle is not applicable for the APG [SGBS].

Equipment Qualification

The seismic classification for the main equipment of the APG [SGBS] is presented in Table T-11C-11. More information is presented in Reference [11] and [26].

The documents relevant to the equipment qualification for the UK HPR1000 are being prepared. { }

Protection against Internal and External hazards

a) Internal hazards

1) Internal Fire

The three trains of APG [SGBS] are arranged in different buildings. Only one train will be affected at a time in the case of internal.

2) Internal Flooding

The blowdown isolation valves are installed high enough that so internal flooding will not affect the safety functions performed by the valves.

3) High Energy Pipe Failures

The pipes of the APG [SGBS] are protected from HEPF through physical separation. Furthermore, the installation and supporting assemblies of the piping limit the swing due to pipe break in order to limit the effect of HEPF.

4) Dropped Loads

Precautions are applied during layout design to avoid dropped loads, such as appropriate design and management of hoisting equipment.

5) Internal Missiles

The APG [SGBS] is protected from the effect of internal missile by the layout design such as set protecting walls between the potential sources of internal missiles and the equipment important to the safety.

6) Internal Explosion

There is no source of explosion used in the APG [SGBS]. The APG [SGBS] is protected from the effects of internal explosions by the layout design.

b) External hazards

1) Earthquake

The equipment of the APG [SGBS] performing safety functions are required to be seismic qualified to ensure their functional ability. The requirements will be provided to the equipment vendor in the form of qualification specifications.

2) External Flooding

The protection against external flooding is taken into consideration in the design of all the buildings where the APG [SGBS] components are located.

3) External Explosion

The effect of external explosion to the APG [SGBS] is protected by the civil building design. The information related to the civil work is presented in Chapter 16.

4) Lighting and Electromagnetic Interference

This hazard is mainly resisted by I&C and electrical systems design. There is no special measure used in the APG [SGBS].

5) Airplane Crash

Airplane crash protection of the APG [SGBS] shall be realised by the building structures accommodating the system. Furthermore the parts of the APG [SGBS] that perform safety functions should be arranged in buildings which are able to withstand the vibration generated by the APC. The effect of

APC on the APG [SGBS] will be analysed in chapter 18.

Commissioning

Initial testing (e.g. factory acceptance tests) of components before delivery to site shall be undertaken to ensure the safety functions of these components can be properly performed. The design requirements will be provided to the equipment vendor in the form of technical specifications.

After the components have been delivered to the site, the commissioning tests will be implemented to validate the operability of individual components and system functions [14].

The types of commissioning tests are the same as mentioned in Sub-chapter 11.3.3.5.2.

At the current stage, the documents related to the commissioning of the UK HPR1000 are being prepared. {
}

Examination, Inspection, Maintenance and Testing

The system operating configuration needs to be continuously monitored to assist the operators to be aware of system status and act immediately under abnormal conditions. The parameters of the blowdown function and cooling function should be monitored, as well as status of components that perform safety functions [14].

An initial maintenance plan will be formulated after the related APG [SGBS] equipment suppliers provide data feedback.

Periodically internal inspections, pressure tests and non-destructive tests are performed to ensure the availability and reliability of the blowdown isolation valves and transfer pipeline control valves [14].

Periodic tests should be implemented for equipment and components that perform safety functions:

a) Blowdown isolation valves (functional testing);

b) Transfer pipeline control valves (functional testing).

Special Thermal-Hydraulic Phenomena

The applicable hydraulic phenomenon for the APG [SGBS] is the boiler effect.

The containment isolation valves of the blowdown pipeline are gate valves. In order to ensure the blowdown function of the APG [SGBS] to support secondary water chemistry control, by-passes are designed for these gate valves, to ensure these valves can be opened when the pressure of the SGs is increasing.

Material Selection

The APG [SGBS] pipes and equipment are made of carbon steel or stainless steel [11].

For the regenerative heat exchanger tube, stainless steel is used to prevent the effects of corrosion on equipment availability.

Under the effect of the demineraliser ion exchange resin, the pH value of the blowdown water downstream the cationic demineralisers is low. Thus, demineralisers and the downstream components shall be made of strong acid resistant materials. Therefore, stainless steel is selected.

The filters are made of stainless steel to avoid the effect of corrosion products in the blowdown water. The other components of the APG [SGBS] can be made of carbon steel.

Insulation

Insulation considerations are applied to the APG [SGBS] part upstream of the heat exchanger (included), to meet the environmental condition requirements [26].

This is applicable to the APG [SGBS] pipelines and equipment with a fluid temperature greater than 60°C.

Decommissioning

The principles and methodology are presented in Chapter 24 (Decommissioning). The design of the APG [SGBS] will take these principles and methodology into account. The design result and relevant analysis will be presented in the safety case of Chapter 24.

11.3.5.6 Functional Diagram

The simplified functional diagram is presented in Appendix 11B Figure F-11B-4. The detailed functional diagram is presented in Reference [28].

11.3.6 ALARP Assessment

The general safety engineering principles have been developed and delivered to the assessor for preliminary assessment at the end of Step 2 of GDA to make sure that the high level safety requirements can meet the UK context. At the same time, various technical areas are being developed simultaneously, such as the hazard schedule, fault schedule, probabilistic safety assessment, human factors, instrumentation and control, etc. A systematic review will be carried out during Step 3 of GDA since the current design result may be affected by the above factors.

If any shortfall is identified during the systematic technical review, an effort will be made in the form of the ALARP analysis to reduce the risk as low as reasonable practicable.

Some Relevant Good Practices (RGPs) based on the UK context such as IAEA safety standards and HSE guidance (Reference [29]) have been identified during Step 2 of GDA. The consistency analyses between the current design results and these RGPs are on-going. At the current stage, no obvious gap has been identified. However, any lessons learned during GDA, especially from UK context, will be taken into account in further design development.

11.3.7 Concluding Remarks

Sub-chapter 11.3 presents the route map setting out a "direction of moving forward" for the VVP [MSS], ARE [MFFCS] and APG [SGBS].

The design of the UK HPR1000 VVP [MSS], ARE [MFFCS] and APG [SGBS] are mainly based on a reference design which is being constructed in China. The information important to the nuclear safety of the VVP [MSS], ARE [MFFCS] and APG [SGBS] is presented in Sub-chapter 11.3, such as the safety requirements and the preliminary design substantiation. More detailed information is presented in the supporting references.

The safety case and design of the UK HPR1000 VVP [MSS], ARE [MFFCS] and APG [SGBS] will be developed in accordance with the methodology of ALARP, and this sub-chapter will ultimately demonstrate that the VVP [MSS], ARE [MFFCS] and APG [SGBS] have reduced risks ALARP to support the level 3 claim (Claim 3.3.7 - The design of the Steam & Power Conversion System has been substantiated) which is decoupled from the high level objective of the UK HPR1000.

11.4 Steam and Power Conversion System (Non-Safety Related)

11.4.1 Introduction

11.4.1.1 Sub-chapter Route Map

The Sub-chapter 11.4 mainly describes the systems which do not perform safety functions. These systems include:

a) Turbine-Generator Set

b) Circulating Water System (CRF [CWS])

c) Turbine Bypass System (GCT [TBS])

d) Feedwater Deaerating Tank and Gas Stripper System (ADG [FDTGSS])

e) Startup and Shutdown Feedwater system (AAD [SSFS])

f) Condensate Polishing System (ATE [CPS])

The above systems are non-classified, so there is no corresponding route map.

Sub-chapter 11.4 only provides a general description of these systems.

11.4.1.2 Sub-chapter Structure

The general structure of Sub-chapter 11.4 is presented below:

a) Sub-chapter 11.4.1 - introduces the Route Map, sub-chapter structure, chapter interfaces and general design requirements;

b) Sub-chapter 11.4.2 - presents the information on applicable codes and standards of Sub-chapter 11.4;

c) Sub-chapter 11.4.3 - presents the design information of the Turbine-Generator Set;

d) Sub-chapter 11.4.4 - presents the design information of the CRF [CWS] and its components;

e) Sub-chapter 11.4.5 - presents the design information of the GCT [CWS] and its components;

f) Sub-chapter 11.4.6 - presents the design information of the ADG [FDTGSS] and its components;

g) Sub-chapter 11.4.7 - presents the design information of the AAD [SSFS] and its components;

h) Sub-chapter 11.4.8 - presents the design information of the ATE [CPS]) and its components;

i) Sub-chapter 11.4.9 - presents the ALARP Assessment of Sub-chapter 11.4;

j) Sub-chapter 11.4.10 - presents Concluding Remarks of Sub-chapter 11.4.

11.4.1.3 Interfaces with Other Chapters

The PCSR contains various chapters, a number of which contain design information. To help understand the relationship between this sub-chapter and other chapters, the relevant interfaces have been identified and are presented in Table T-11C-1 of Appendix 11C.

11.4.1.4 General Design Requirements

The systems described in Sub-chapter 11.4 are non-classified, they do not perform a safety function. These systems therefore have no design requirements related to nuclear safety.

11.4.2 Applicable Codes and Standards

The systems and equipment described in Sub-chapter 11.4 do not have special design and manufacturing requirements related to nuclear safety, and only need to comply with general industrial codes and standards. Therefore, relevant codes and standards for these systems and equipment are not provided at the GDA stage.

11.4.3 Turbine-Generator Set

Site/Operator specific information. Not applicable to GDA.

11.4.4 Circulating Water System

11.4.4.1 Safety Functional Requirements

The CRF [CWS] is non-classified, it is not required to perform the three main safety functions (control of fuel reactivity, fuel heat removal, confinement of radioactive material).

11.4.4.2 Design Requirements

Not applicable. The CRF [CWS] is not required to perform safety functions.

11.4.4.3 Design Bases

a) The CRF [CWS] is designed to continuously supply cooling water to the condensers of the turbine unit and the Auxiliary Cooling Water System (SEN [ACWS]) under various conditions encountered during power operation.

b) The CRF [CWS] is designed to optimise the cooling water flow rate to the condenser, taking into account site conditions.

c) The CRF [CWS] is designed to meet the discharge temperature and temperature rise regulation requirements.

11.4.4.4 System Description and Operation

11.4.4.4.1 Description of System Configuration

The CRF [CWS] continuously supplies cooling water to cool the turbine exhaust steam that flows into the condenser and to the SEN [ACWS].

The cooling water passes through the drum screens, circulating water pumps, debris filters, the condenser water boxes, and finally discharges to the outlet culverts.

The overall arrangement of the CRF [CWS] allows the condensers to be divided into halves. Such division can be achieved by the shutdown of the associated Circulating Water Pumps (CWPs) and by opening of the siphon break valves.

11.4.4.4.2 Description of Main Equipment

The main equipment of the CRF [CWS] includes Circulating Water Pumps, syphon break valves and debris filters.

a) Circulating water pumps

There are two 50% circulating water pumps in each unit, and the two of them are the same type of concrete volute pumps.

b) Syphon break valve

Three syphon break valves are provided for each circulating water circuit, connected to the outlet waterboxes of the condenser by a common manifold. The operation of the valve is automatically controlled by the operating signals of the circuit water pump. Each valve is provided with an upstream filter and each connection from the manifold to the respective outlet waterbox is fitted with an orifice plate to control the air flow.

c) Debris filters

There are four debris filters. One debris filter is provided in each of the circulating water inlet pipes. They are of a back washing type with the debris discharging into the circulating water outlet pipes. A control panel is provided for each of the debris filters.

11.4.4.4.3 Description of Main Layout

The CRF [CWS] is located in the BMX and Circulating Water Pumping Station (BPW).

The CRF [CWS] is non-classified. There are no special installation requirements related to nuclear safety, it only needs to consider the following general installation requirements:

a) The height difference between the highest point of the condenser drain and the water level on the weir of the seal pit shall be no more than 7.50m. The circulating water culvert is designed according to the overlapping layout.

b) The pipeline layout must avoid collision and interference with each function pipeline of the condenser. The system must reasonably arrange drainage, exhaust and pressure relief devices.

c) The operating convenience and space of the manually operated valves must be considered in the system layout.

11.4.4.4.4 Description of System Interface

<u>Supporting Systems</u>

a) SEO[SSS]

The SEO [SSS] is required to receive drainage from the CRF [CWS].

b) SAR[ICADS]

The SAR [ICADS] is required to provide compressed air for the CRF [CWS] syphon break valves.

User system:

a) CEX [CES]

The CRF [CWS] is required to continuously supply cooling water to the CEX [CES] to cool the turbine exhaust steam that flows into the condenser.

b) SEN [ACWS]

The CRF [CWS] is required to continuously supply cooling water to the SEN [ACWS] to cool the heat exchanger of the Conventional Island Closed Cooling Water System SRI [CICCWS].

11.4.4.4.5 Description of Instrumentation and Control

Not applicable: the CRF [CWS] does not have any dedicated instrumentation and control related to nuclear safety, it only needs conventional instrumentation and control.

11.4.4.4.6 Description of System Operation

During normal operation, no actual operation of the CRF [CWS] is involved except for occasional cleaning of the debris filter due to high differential pressure.

Particular Steady Operation: the turbine generator can be continuously operated with one CWP. Under this condition, a single circulating water flow path exists in each condenser shell with a consequent worsening of the condenser vacuum which will result in load reduction.

11.4.4.5 Preliminary Design Substantiation

Not applicable: the CRF [CWS] does not have any dedicated requirements (EMIT) related to nuclear safety, it only needs conventional requirements.

11.4.4.6 Functional Diagram

The simplified functional diagram is presented in Appendix 11B Figure F-11B-5.

11.4.5 Turbine Bypass System

11.4.5.1 Safety Functional Requirements

The GCT [TBS] is non-classified, it is not required to perform the three main safety functions (control of fuel reactivity, fuel heat removal, confinement of radioactive material).

11.4.5.2 Design Requirements

Not applicable. The GCT [TBS] is not required to perform nuclear safety functions.

11.4.5.3 Design Bases

a) The GCT [TBS] is designed with the capacity to bypass 85% of the full load steam flow to the condenser.

b) The GCT [TBS] participates in heat up and cool down operations for the switch to residual heat removal mode during unit startup and shutdown.

c) The GCT [TBS] contributes to controlling the secondary pressure during turbine startup and synchronization.

d) The total flow capacity of the GCT [TBS], in combination with bypass valve response time contributes to prevent primary circuit heat-up and reduce challenges to the VDA [ASDS] following reactor trip, load rejection or turbine trip from 100% power without reactor trip.

11.4.5.4 System Description and Operation

11.4.5.4.1 Description of System Configuration

All of the steam exhaust travels into condenser through the GCT [TBS] which consist of steam pipes, isolation valves, control valves and a drainage system. There are two bypass pipes connected with both ends of the main steam header and sixteen exhaust branch pipes connected to the diffusers of the condenser. Each pipe has an isolation valve with is normally open, a bypass control valve and a diffuser.

The capacity of the GCT [TBS] is 85% of the rated main steam flowrate which allows the reactor to operate independently without the turbine system.

11.4.5.4.2 Description of Main Equipment

The main equipment of the GCT [TBS] includes the bypass control valves, bypass isolation valves and spray water control valves.

a) Bypass control valves

The GCT [TBS] allocates sixteen bypass control valves through which main steam exhaust travels into the condenser.

To avoid excessive emissions of steam caused by unexpected opening of the control valves, the consequences of unexpected pressure relief of the main steam system are considered in the analysis of nuclear safety. The maximum capacity of any single steam bypass control valve will not exceed 162 kg/s at 8.9 MPa(g).

The characteristics of these valves are linear, valves will fail to close in condition of power loss or air loss. These sixteen valves are divided into four banks.

b) Bypass isolation valves

Each bypass control valve is connected with a bypass isolation valve which is used for isolating the steam pipe and condenser. Isolation valves are operated manually and stay open during normal conditions.

c) Spray water control valves

Two spray water control valves are used to control the flow of cooling condensate through the sixteen diffusers on both sides of the condenser (each side contains eight diffusers).

11.4.5.4.3 Description of Main Layout

The GCT [TBS] is located in the BMX. The GCT [TBS] is non-classified. There are no special installation requirements related to nuclear safety, it only needs to consider the following general installation requirements:

a) The layout of the GCT [TBS] meets the maintenance and replacement requirements of equipment throughout their lifetime.

b) The layout of equipment such as valves allows for easy testing, operating and maintenance. There must be drain points at lower place and vent points at higher place.

11.4.5.4.4 Description of System Interface

<u>Supporting Systems:</u>

a) CEX[CES]

The CEX [CES] is required to supply cooling water to the spray water control valve of the GCT [TBS].

b) VPU[MSDS]

The VPU [MSDS] is required to transport main steam to the GCT [TBS].

c) SEK [WFCSCI]

The Waste Fluid Collection System for the Conventional Island (SEK [WFCSCI]) is required to collect the discharged waste liquid from the GCT [TBS].

<u>User system:</u>

a) CEX [CES]

The CEX [CES] is required to receive bypass steam and drainage from the GCT [TBS].

11.4.5.4.5 Description of Instrumentation and Control

Not applicable: the GCT [TBS] does not have any dedicated instrumentation and control related to nuclear safety, it only needs conventional instrumentation and control.

11.4.5.4.6 Description of System Operation

During the normal plant operation, the path of steam to the condenser is shut.

At the range of 15%~100% Rated Thermal Output (RTO), the GCT [TBS] can make the Nuclear Steam Supply System (NSSS) adapt to: sharp load decreases of the turbine, step changes of load reduction which exceed 10% RTO and linear changes of that with over 5%RTO/min, as well as turbine load rejection to the house load. These functions prevent emergency shutdown of the plant and avoid valves of VDA [ASDS] opening.

The GCT [TBS] can avoid reactor trip and prevent the VDA [ASDS] from opening in condition of turbine trip, recover the RCP [RCS] to zero power status or to the operating condition with the final power setting value.

11.4.5.5 Preliminary Design Substantiation

Not applicable: the GCT [TBS] does not have any dedicated requirements (EMIT) related to nuclear safety, it only needs conventional requirements.

11.4.5.6 Functional Diagram

The simplified functional diagram is presented in Appendix 11B Figure F-11B-6.

11.4.6 Feedwater Deaerating Tank and Gas Stripper System

11.4.6.1 Safety Functional Requirements

The ADG [FDTGSS] is non-classified, it is not required to perform the three main safety functions (control of fuel reactivity, fuel heat removal, confinement of radioactive material).

11.4.6.2 Design Requirements

Not applicable. The ADG [FDTGSS] is not required to perform safety functions.

11.4.6.3 Design Bases

a) The ADG [FDTGSS] is designed to heat and deaerate feedwater.

b) The ADG [FDTGSS] is designed to maintain a storage capacity to meet any transient mismatch between steam generator requirements and the available condensate supply.

c) The ADG [FDTGSS] is designed to receive the leak off flow from the APA [MFPS] pump, the drains from the HP heater and MSR, and condensate from the APG [SBS].

d) The ADG [FDTGSS] is designed to provide sufficient head at the feedwater pumps suction under all operating conditions.

11.4.6.4 System Description and Operation

11.4.6.4.1 Description of System Configuration

The ADG [FDTGSS] consists of a single body feedwater tank equipped with an integrated deaerator. Three systems supply steam to the feedwater tank, including:

a) The Auxiliary Steam Distribution System (SVA [ASDS]), which is used for startup heating of the storage tank;

b) The VPU[MSDS], which is used for transient operations such as turbine trip, load rejection, or low load operation;

c) Steam bled from the cold reheat to the MSR line shall be used for normal operation.

11.4.6.4.2 Description of Main Equipment

The main equipment of the ADG [FDTGSS] includes the deaerator and recirculation pump.

a) Deaerator

The deaerator is a steel cylindrical pressure vessel fitted with two heads and supported on four sets of feet. To permit thermal expansion or contraction of the deaerator one set is anchored with the other three sets free to slide. This arrangement allows the deaerator to move axially in either direction away from the anchor point.

The deaerator is equipped with a group of safety valves. Once the pressure exceeds a certain value, the safety valves will open to discharge excess steam to the atmosphere.

b) Recirculation Pump

The pump is provided with a 300mm suction connection on the deaerator shell, located at the end of the tank remote to the single spray in service during startup, ensuring maximum circulation of the feedwater within the tank. The recirculation pump discharges through a 200mm pipe into the main condensate feed line at the deaerator inlet.

11.4.6.4.3 Description of Main Layout

The ADG [FDTGSS] is non-classified. There are no special installation requirements related to nuclear safety, it only needs to consider the following general installation requirements.

The layout of equipment must be easy to test, operate and maintain. The deaerator and recirculation pump are installed in the BMX.

11.4.6.4.4 Description of System Interface

Supporting Systems:

a) ABP [LPFHS]

The ABP [LPFHS] is required to provide condensate water for the ADG [FDTGSS].

b) CEX[CES]

The CEX [CES] is required to receive drains and vents for the ADG [FDTGSS].

c) SVA [ASDS]

The SVA [ASDS] is required to provide auxiliary steam for the ADG [FDTGSS].

d) VPU[MSDS]

The VPU [MSDS] is required to provide main steam for the ADG [FDTGSS].

e) SEK [WFCSCI]

The SEK [WFCSCI] is required to receive drainage for the ADG [FDTGSS].

f) GPV [TSDS]

The GPV [TSDS] is required to provide bled steam for the ADG [FDTGSS].

g) Feedwater Chemical Sampling System (SIT [FCSS])

The SIT [FCSS] is required to chemical sampling for the ADG [FDTGSS].

h) Chemical Reagents Injection System (SIR [CRIS])

The SIR [CRIS] is required to provide reagent injection for the ADG [FDTGSS].

i) Conventional Island Demineralised Water Distribution System (SER [CIDWDS])

The SER [CIDWDS] is required to provide make-up water for the ADG [FDTGSS].

User system:

a) APA [MFPS]

The ADG [FDTGSS] is required to feed the APA [MFPS] pump and collect the minimum flow.

b) AAD [SSFS]

The ADG [FDTGSS] is required to feed the AAD [SSFS] pump and collect the minimum flow.

c) AHP [HPFHS]

The ADG [FDTGSS] is required to receive drain returns and vents of the AHP [HPFHS].

d) APG [SGBS]

The ADG [FDTGSS] is required to receive condensate return from the APG [SGBS].

e) ARE [MFFCS]

The ADG [FDTGSS] is required to receive recirculation for the startup condition from theARE [MFFCS].

11.4.6.4.5 Description of Instrumentation and Control

Not applicable: the ADG [FDTGSS] does not have any dedicated instrumentation and control related to nuclear safety, it only needs conventional instrumentation and control.

11.4.6.4.6 Description of System Operation

Normal operating conditions are at the turbine generator maximum continuous electrical output with no section of the feed train bypassed.

The pressure in the feedwater tank drops at the beginning of the transient because of a loss of the bleeding and then returns to the hot shutdown set-point value with the live steam sustaining it.

The flow of the CEX [CES] is stabilised by the regulator at a value dependent on the thermal power of the hot shutdown of the reactor.

11.4.6.5 Preliminary Design Substantiation

Not applicable: the ADG [FDTGSS] does not have any dedicated requirements (EMIT) related to nuclear safety, it only needs conventional requirements.

11.4.6.6 Functional Diagram

The simplified functional diagram is presented in Appendix 11B Figure F-11B-7.

11.4.7 Startup and Shutdown Feedwater System

11.4.7.1 Safety Functional Requirements

The AAD [SSFS] is non-classified, it is not required to perform the three main safety functions (control of fuel reactivity, fuel heat removal, confinement of radioactive material).

11.4.7.2 Design Requirements

Not applicable. The AAD [SSFS] is not required to perform safety functions.

11.4.7.3 Design Bases

The system is designed to supply feedwater to the SGs during normal plant startup, shutdown or hot standby.

The system is designed to deliver sufficient flow (up to 5.2% of normal flow rate) to the SGs to avoid the actuation of the ASG [EFWS] following transients in the event of normal/standby auxiliary transformer changeover.

11.4.7.4 System Description and operation

11.4.7.4.1 Description of System Configuration

The AAD [SSFS] system is composed of:

a) A fixed speed motor-pump set in order to supply feedwater downstream of the AHP [HPFHS] heaters.

b) A lube oil system in order to lubricate the motor-pump set.

c) A minimum flow line in order to prevent the pump from running below its minimum flow rate.

d) A thermal conditioning line in order to warm the pump during the plant operation and thus to keep the AAD [SSFS] pump on standby and ready for a quick start.

11.4.7.4.2 Description of Main Equipment

The main equipment of the AAD [SSFS] includes the startup feedwater pump and suction pump strainer.

a) Startup Feedwater Pump

The startup feedwater pump is a single speed multistage horizontal barrel type centrifugal pump (one per unit). The pump takes suction from the ADG [FDTGSS] deaerator tank. It is a motor driven pump that injects water to the steam generators via the very low load regulating valves of the ARE [MFFCS] during plant startup, hot standby and shutdown conditions, and during transients in the event of main feed water system APA [MFPS] unavailability.

The pump is equipped with two mechanical seals that are equipped with a cooling jacket chamber, and it is equipped with a pad journal and thrust bearings. The lubrication is ensured by an electrical pump (startup) and a mechanical driven pump.

The rated flowrate of the pump is about 382.3 m^3/h.

b) Suction pump strainer

The strainer prevents debris from entering the pump. A differential pressure transmitter enables monitoring of the clogging of the strainer, and initiates an alarm in case of high-pressure drop.

The strainer is used during the unit startup phase, when the risk of having debris enter the pump is high. However, when the pump is in standby, the strainer is bypassed. Limit switches at the strainer by-pass valve enable the operator to be warned of any misalignment.

11.4.7.4.3 Description of Main Layout

The AAD [SSFS] is non-classified. There are no special installation requirements related to nuclear safety, it only needs to consider the following general installation requirements.

The layout of equipment must be easy to test, operate and maintain. The startup feedwater pump and strainer are installed in the BMX.

11.4.7.4.4 Description of System Interface

Supporting Systems:

a) SEK [WFCSCI]

The SEK [WFCSCI] is required to receive drainage for the AAD [SSFS].

b) ADG [FDTGSS]

The ADG [FDTGSS] is required to provide feedwater for the AAD [SSFS].

User system:

a) ARE [MFFCS]

The AAD [SSFS] is required to provide feedwater for the SGs through the header of the ARE [MFFCS].

11.4.7.4.5 Description of Instrumentation and Control

Not applicable: the AAD [SSFS] does not have any dedicated instrumentation and control related to nuclear safety, it only needs conventional instrumentation and control.

11.4.7.4.6 Description of System Operation

During normal plant startup, feedwater is supplied by the startup feedwater pump until the transition is made to the main feedwater pumps.

During normal plant shutdown, feedwater is supplied by the startup feedwater pump during the transition from the main feedwater pumps to RHR connection.

The AAD [SSFS] remains in standby during normal unit operation. In the event of normal/standby auxiliary transformer changeover, the three main feedwater pumps are tripped and the startup feedwater pump takes over automatically.

11.4.7.5 Preliminary Design Substantiation

Not applicable: the AAD [SSFS] does not have any dedicated requirements (EMIT) related to nuclear safety, it only needs conventional requirements.

11.4.7.6 Functional Diagram

The simplified functional diagram is presented in Appendix 11B Figure F-11B-8.

11.4.8 Condensate Polishing System

11.4.8.1 Safety Functional Requirement

The ATE [CPS] is non-classified, it is not required to perform the three main safety functions (control of fuel reactivity, fuel heat removal, confinement of radioactive material).

11.4.8.2 Design Requirements

Not applicable. The ATE [CPS] is not required to perform nuclear safety functions.

11.4.8.3 Design Bases

The ATE [CPS] is used to remove traces of silicon, copper, iron and dissolved salts from the condensate to ensure the feedwater and steam quality meets the requirements. It also protects the secondary systems from contamination when there is a condenser tube leakage.

11.4.8.4 System Description and operation

11.4.8.4.1 Description of System Configuration

The ATE is connected via a bypass with the condensate header, on which no isolation valve is installed, between the ATE [CPS] inlet and outlet. This ensures the condensate supply for the secondary circulate under any fault condition of the ATE [CPS].

The condensate water chemistry specification is presented in PCSR Chapter 21.

11.4.8.4.2 Description of Main Equipment

a) Cation Polishing Units

There are five parallel connected cation polishing units to receive condensate from the CEX [CES]. A resin catcher is arranged for each mixed bed to prevent the leakage of resin particles.

b) Mixed Bed Polishing Units

There are five parallel connected mixed bed polishing units, for each unit to receive outlet water from the cation polishing units. A resin catcher is arranged for each mixed bed to prevent the leakage of resin particles.

c) Regeneration Unit

The cation resin and anion resin for the polishing units are externally regenerated. The regeneration unit consists of the regeneration device for the cation bed resin and mixed bed resin.

d) Booster Pumps

There are 3×50% booster pumps in the ATE [CPS]. The capacity of booster pumps ensures a certain overflow in the condensate header; the pump head is able to compensate for the total pressure drop of the ATE [CPS].

e) Rinse Recycle Pumps

The two rinse recycle pumps fulfill the recycle requirement of the outlet water of the cation polishing units and mixed bed polishing units.

11.4.8.4.3 Description of Main Layout

The cation polishing units, mixed bed polishing units, booster pumps, rinse recycle pumps and regeneration unit are located in the BMX. Other equipment of the ATE [CPS] is located outside the condensate polishing plant.

11.4.8.4.4 Description of System Interface

Supporting Systems:

a) NI Demineralised Water Distribution System (SED [DWDS(NI)])

The SED [DWDS (NI)] is required to provide demineralised water for the ATE [CPS].

b) Service Compressed Air Distribution System (SAT [SCADS])

The SAT [SCADS] is required to provide service compressed air for the ATE [CPS].

c) Instrument Compressed Air Distribution System (SAR [ICADS])

The SAR [ICADS] is required to provide instrument compressed air for the ATE [CPS].

d) Potable Water System (SEP [PWS (NI)])

The SEP [PWS (NI)] is required to provide fresh water for the ATE [CPS].

e) Feedwater Chemical Sampling System (SIT [FCSS])

The SIT [FCSS] is required to take samples from the ATE [CPS].

f) Waste Fluid Collection System for Conventional Island (SEK [WFCSCI])

The SEK [WFCSCI] is required to receive drainage for the ATE [CPS].

User system:

a) Condensate Extraction System (CEX [CES])

The ATE [CPS] is required to provide clean-up condensate for the CEX [CES].

11.4.8.4.5 Description of Instrumentation and Control

The condensate flow of the ATE [CPS] is monitored by the flowmeter installed on the outlet of the condensate pump. A signal from the flowmeter is received by the PLC. The PLC uses this signal to determine the number of polishing units to place “on-line” and the number of booster pumps to start up.

11.4.8.4.6 Description of System Operation

Condensate enters into the ATE [CPS] via the main condensate pipe and loops through the cation beds and the mixed beds so as to remove the suspended solids and ionic impurities. The purified condensate is pumped back to the main condensate pipe by the condensate booster pumps.

The ATE [CPS] is put into operation during the startup of the plant. During plant power operation and shutdown, the ATE [CPS] is in the standby state.

In the event of condenser leakage, the ATE [CPS] is put into operation to prevent the impurities in the condensate and give the operator more time for the flexibility of operation before the shutdown.

11.4.8.5 Preliminary Design Substantiation

Not applicable. The ATE [CPS] is not required to perform nuclear safety functions.

11.4.8.6 Functional Diagram

The simplified functional diagram is presented in Appendix 11B Figure F-11B-9.

11.4.9 ALARP Assessment

The demonstration of ALARP is first based on a review of the design against Relevant Good Practice (RGP), OPEX and international guidance, such as HSE guide (Reference [29]). The systems and their components described in Sub-chapter 11.4 are non-classified. At the current stage, there are no significant gaps identified. However, any lesson learned during GDA will be taken into account in the future design reviews and development.

The general safety engineering principles are developed, and the design reviewed against these principles, to ensure that the design is suitable for the UK context.

Various technical assessments are currently ongoing, such as the hazard schedule, probabilistic safety assessment, human factors, and the assessments may identify opportunities for further enhancement of the design

A systematic review will therefore be carried out following completion of the technical assessments. If any gap (or potential enhancement) is identified during the technical review, analysis and optioneering will be carried out and all reasonably practicable improvements will be implemented to reduce the risk as low as reasonably practicable { }.

11.4.10 Concluding Remarks

Sub-chapter 11.4 provides an introduction for the design information of the steam and power conversion system (non-safety related) in the UK HPR1000 nuclear power plant. Since these systems are non-classified and do not relate to any relevant claims, they are introduced in general from the aspects of system composition, operation etc.

11.5 Concluding Remarks

Chapter 11 provides an introduction for the design information of the steam and power conversion system in the UK HPR1000 nuclear power plant and demonstrates that the systems satisfy the performance requirements. Concluding remarks of each sub-chapter can be found in sections 11.3.7 and 11.4.10.

11.6 References

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[19] CGN, VVP-Main Steam System Design Manual Chapter 4 System and Component Design, GHX17VVP004DNHX45GN, Revision A, June 2018.

[20] CGN, VVP-Main Steam System Design Manual Chapter 2 Brief Introduction to the System, GHX17VVP002DNHX45GN, Revision A, 2018.

[21] CGN, VVP-Main Steam System Design Manual Chapter 9 Flow Diagrams, GHX17VVP009DNHX45GN, Revision B, June 2018.

[22] CGN, APG-Steam Generator Blowdown System Design Manual Chapter 2 Brief Introduction to the System, GHX17APG002DNHX45GN, Revision A, 2018.

[23] CGN, ARE-Main Feedwater Flow Control System Design Manual Chapter 5 Layout Requirements and Environment Condition, GHX17ARE005DNHX45GN, Revision A, 2018.

[24] CGN, ARE-Main Feedwater Flow Control System Design Manual Chapter 4 System and Component Design, GHX17ARE004DNHX45GN, Revision A, June 2018.

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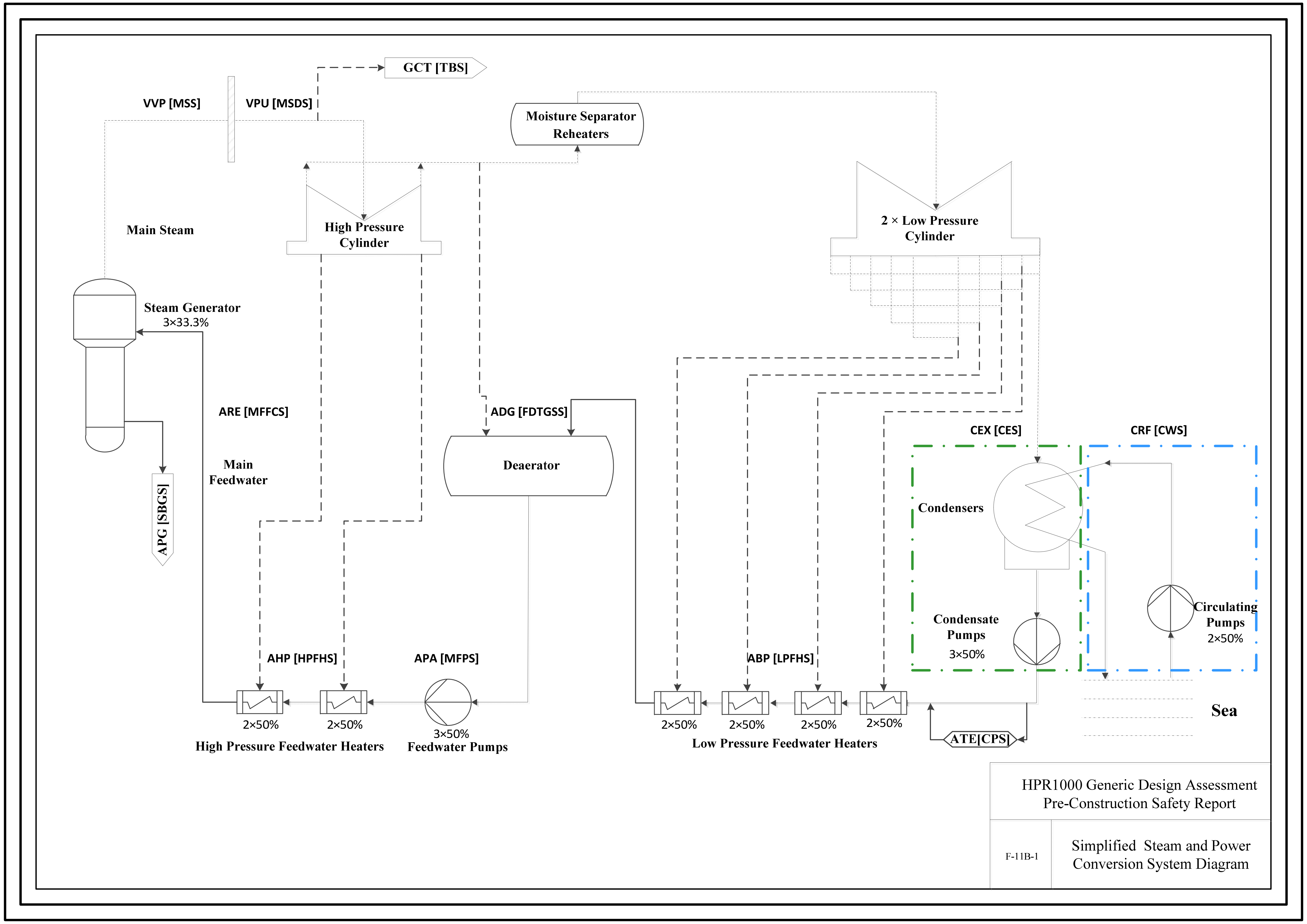
[29] HSE, The safe isolation of plant and equipment (HSG 253), ISBN 978 0 7176 6171 8, second edition, 2006.

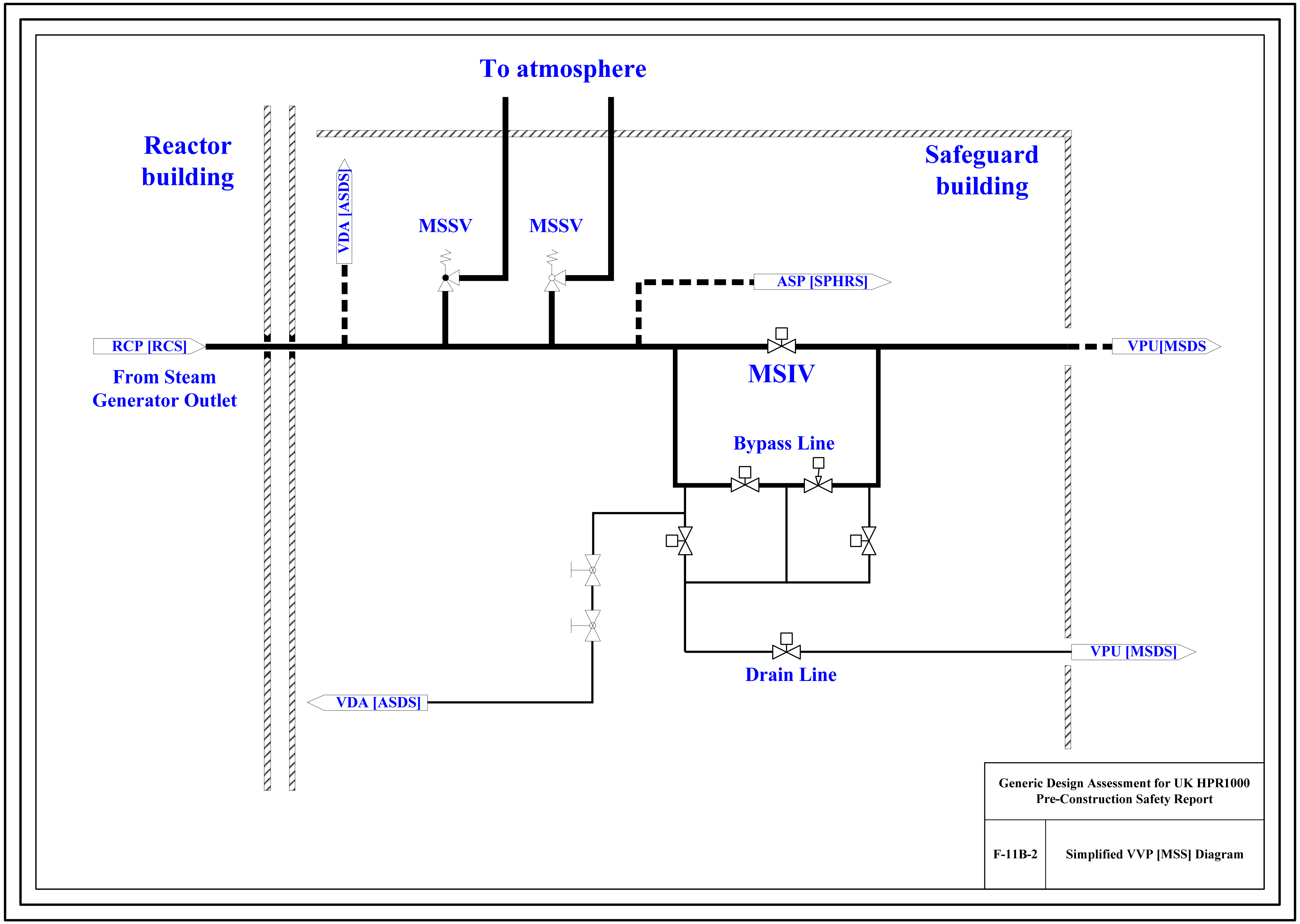
Appendix 11A Route Map

Claim		Sub-claim		Argument		PCSR Links	Evidence
3.3.7	*The design of the Steam & Power Conversion System has been substantiated.*	3.3.7A	*The safety functional requirements (Design Basis) have been derived for the system.*	3.3.7A-1	*The system specific design principles are identified based on relevant good practice.*	Sub-chapter 11.3.2	References [7], [8], [11]
				3.3.7A-2	*The system design basis (requirements) has been derived from the safety analysis in accordance with the general design and safety principles.*	Sub-chapter 11.3.x.1 11.3.x.2	References [7], [8], [11] References [18], [23], [26]
				3.3.7A-3	*The Safety Class of the system and associated structures and components has been identified from the safety analysis.*	Sub-chapter 11.3.x.5	References [7], [8], [11]
		3.3.7B	*The system design satisfies the safety functional requirements.*	3.3.7B-1	*Appropriate design methods have been identified for the system including design codes and standards.*	Sub-chapter 11.3.x.2	References [7], [8], [11]
				3.3.7B-2	*The system has been analysed using the appropriate design methods and meet the design basis requirements.*	Sub-chapter 11.3.x.5	References [19], [24], [27] References [12], [13], [14] References [21], [25], [28]
				3.3.7B-3	*The system analysis recognises interface requirements and effects from/to interfacing systems.*	Sub-chapter 11.3.x.4	References [19], [24], [27]
		3.3.7C	*All reasonably practicable measures have been adopted to improve the design.*	3.3.7C-1	*The system meets the requirements of the relevant design principles (generic and system specific) and therefore of relevant good practice.*	Sub-chapter 11.3.x.5	References [7], [8], [11] References [19], [24], [27] References [12], [13], [14]
				3.3.7C-2	*PSA indicates the system is not a disproportionate contributor to risk.*	Sub-chapter 11.3.6	/
				3.3.7C-3	*Design improvements have been considered and any reasonably practicable changes implemented.*	Sub-chapter 11.3.6	/
		3.3.7D	*The system performance will be validated by suitable commissioning and testing.*	3.3.7D-1	*The system has been designed to take benefit from a suite of pre-construction tests, to provide assurance of the initial quality of the manufacture.*	Sub-chapter 11.3.x.5	References [19], [24], [27]
				3.3.7D-2	*The system has been designed to take benefit from a suite of commissioning tests, to provide assurance of the initial quality of the build.*	Sub-chapter 11.3.x.5	References [12], [13], [14]
		3.3.7E	*The effects of ageing of the system have been addressed in the design and suitable examination, inspection, maintenance and testing specified.*	3.3.7E-1	*An initial EMIT strategy has been developed for this system, identifying components that are expected to be examined, maintained, inspected and tested.*	Sub-chapter 11.3.x.5	References [12], [13], [14]
				3.3.7E-2	*The components that cannot be replaced have been shown to have adequate life, which includes the requirements during decommissioning.*	Sub-chapter 11.3.x.5	References [12], [13], [14]

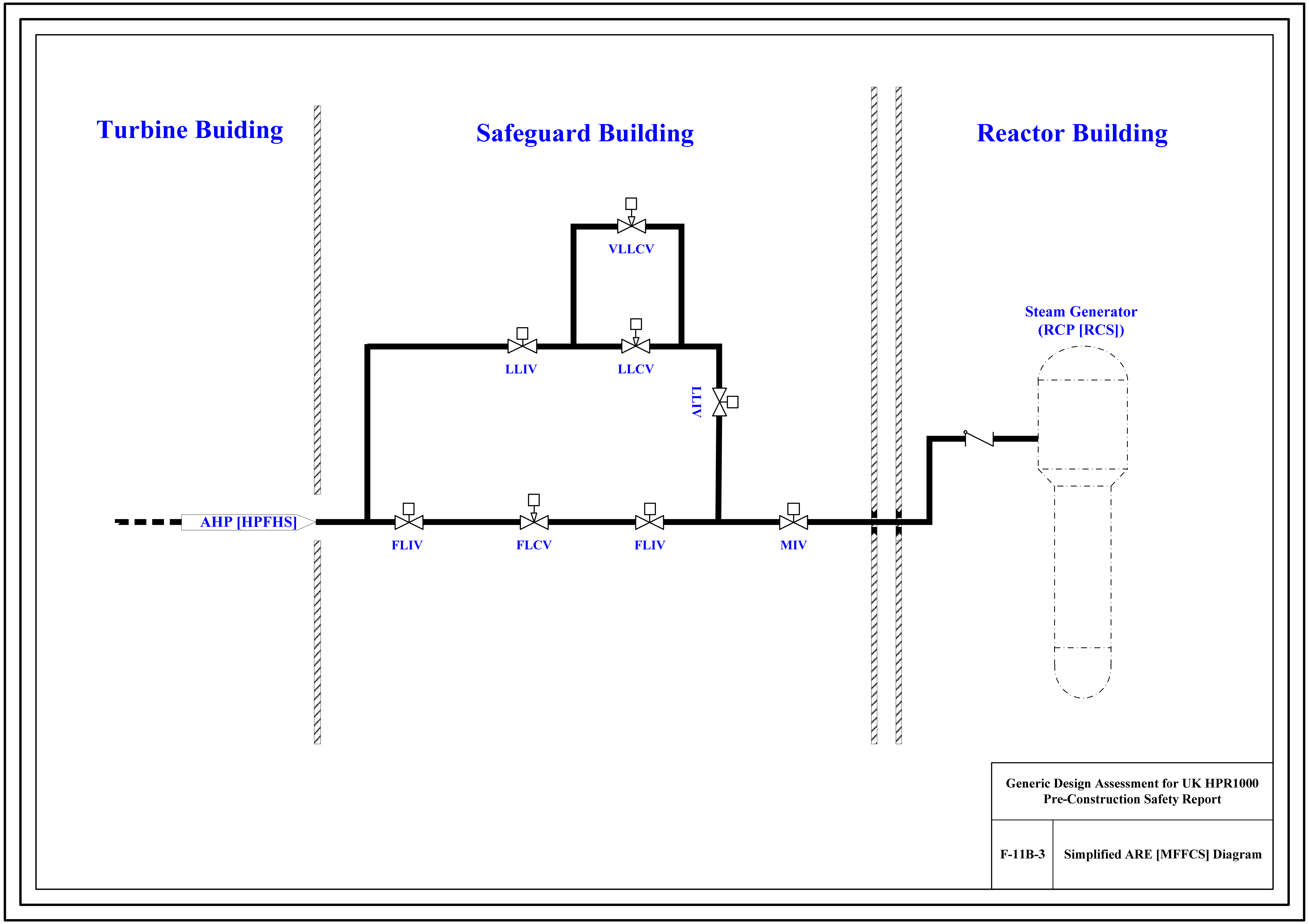
Appendix 11B Functional Diagrams



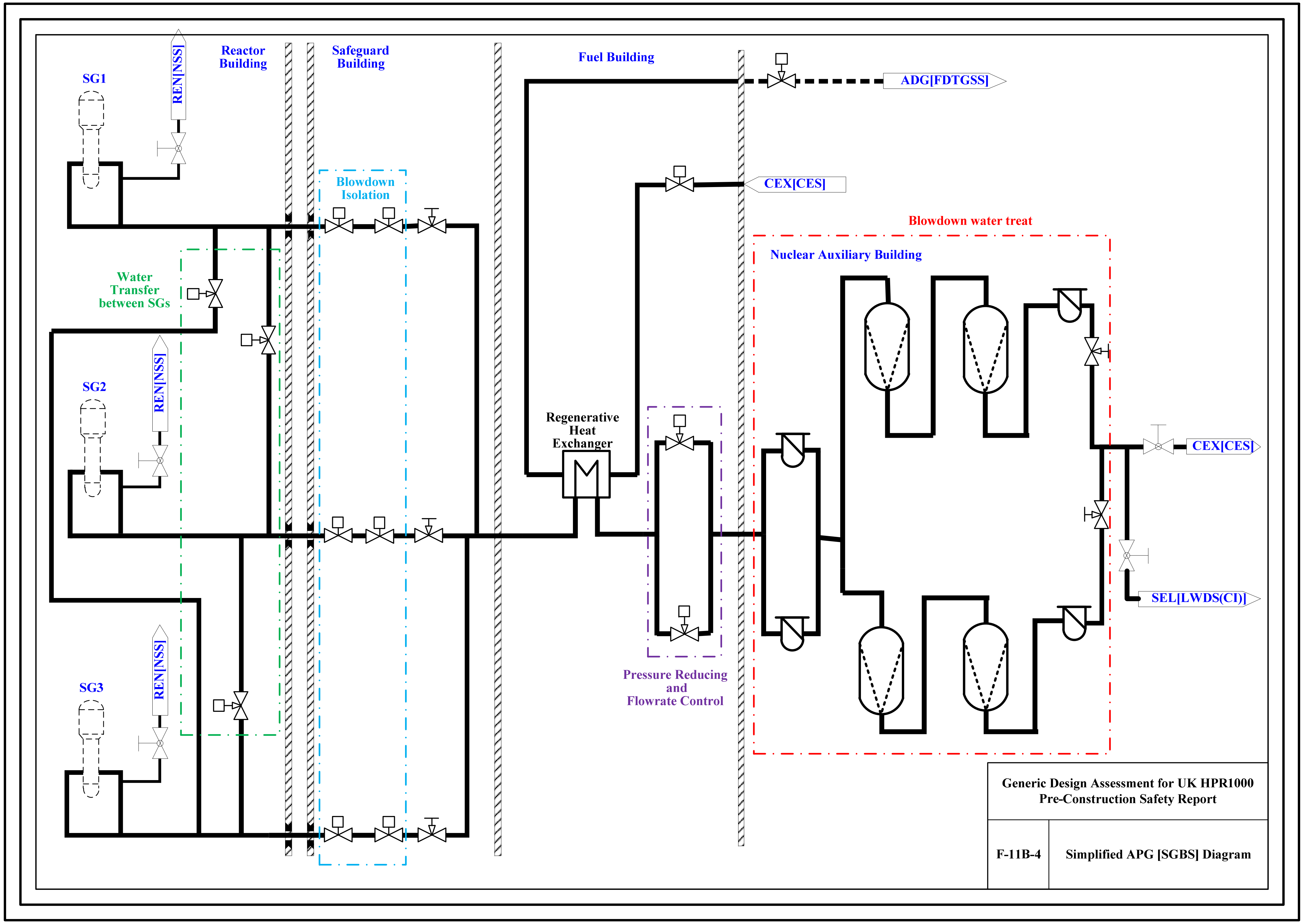
F-11B-1 Simplified Diagram of Steam and Power Conversion System



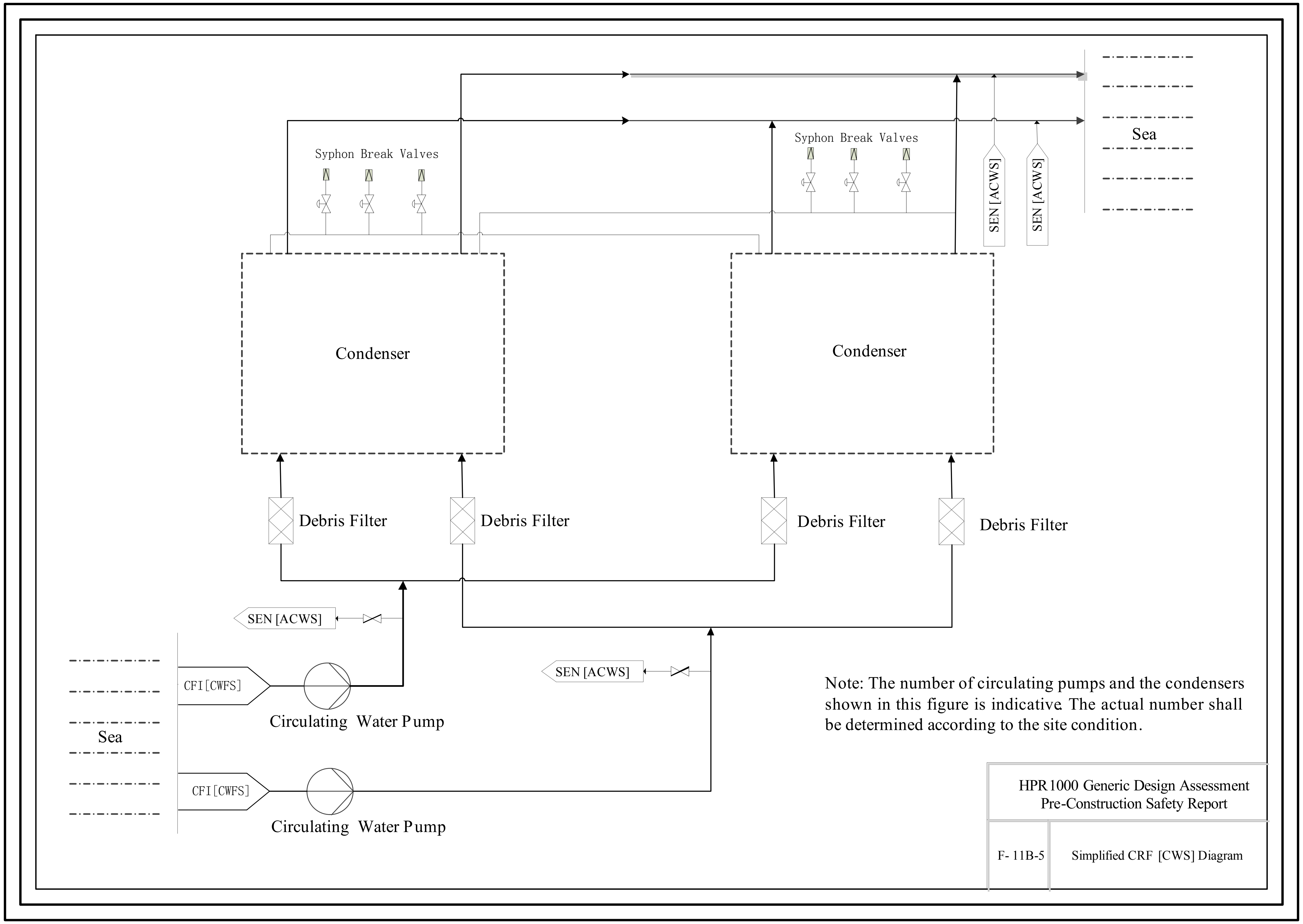
F-11B-2 Simplified Diagram of VVP [MSS]



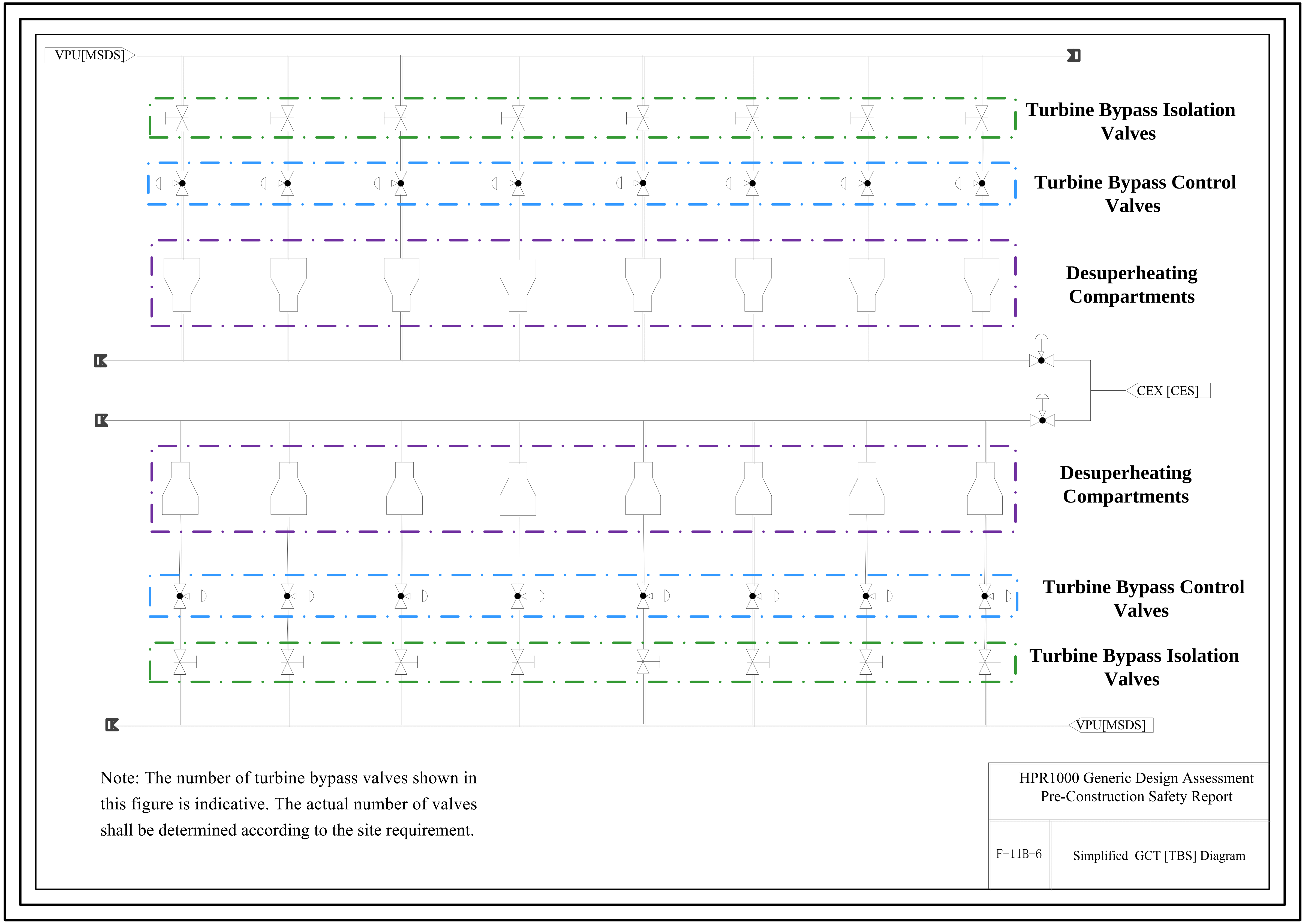
F-11B-3 Simplified Diagram of ARE [MFFCS]



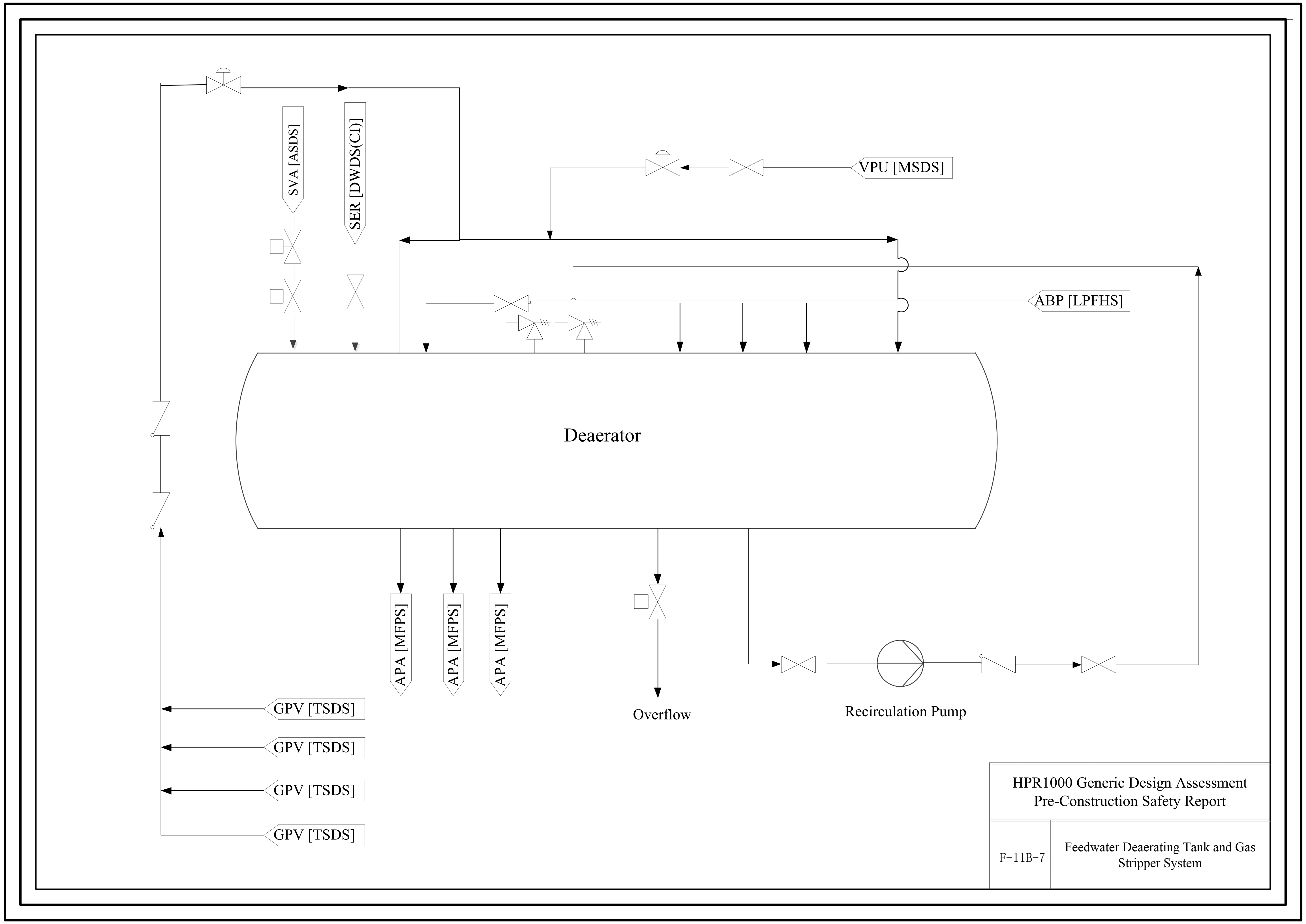
F-11B-4 Simplified Diagram of APG [SGBS]



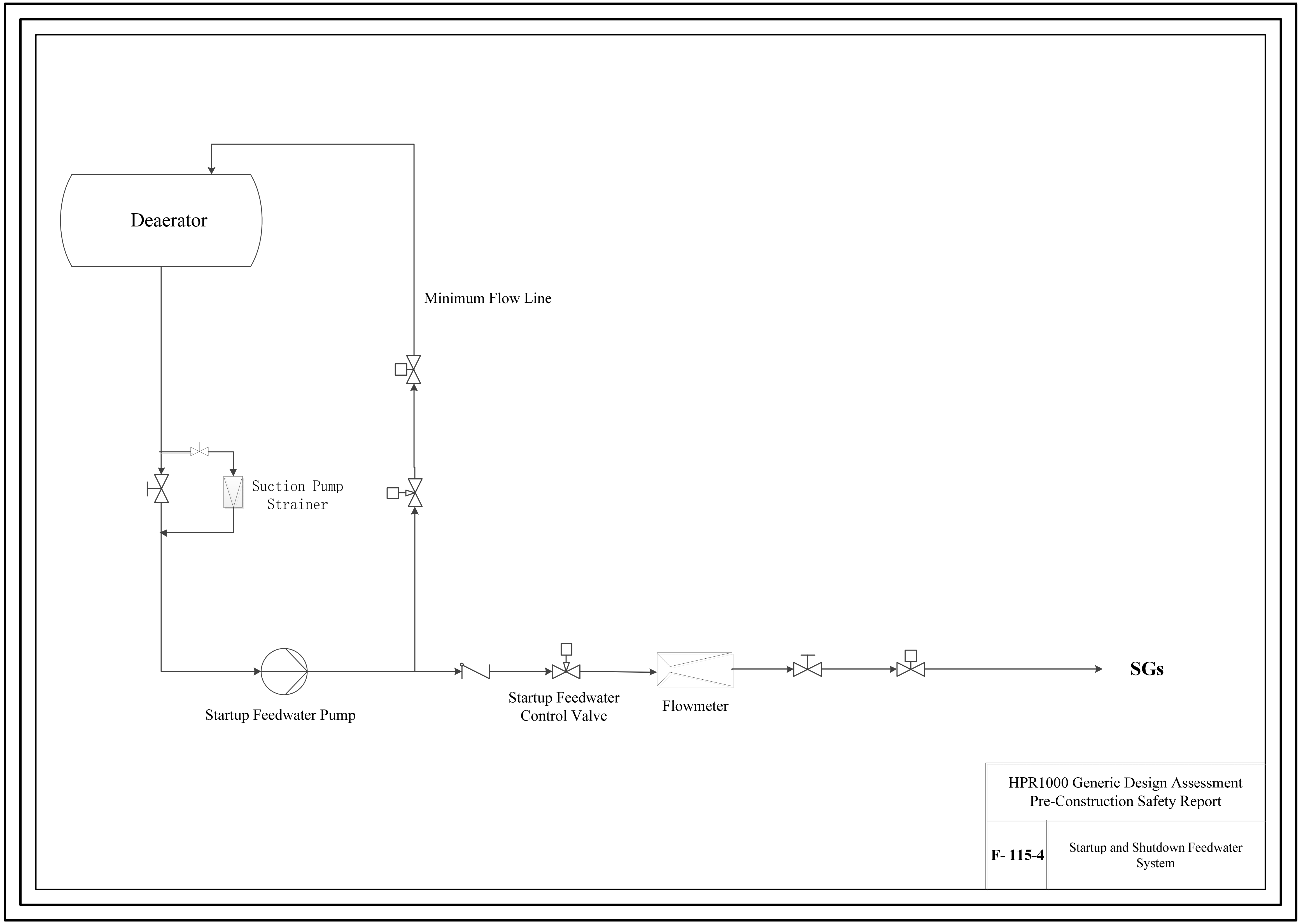
F-11B-5 Simplified Diagram of CRF [CWS]



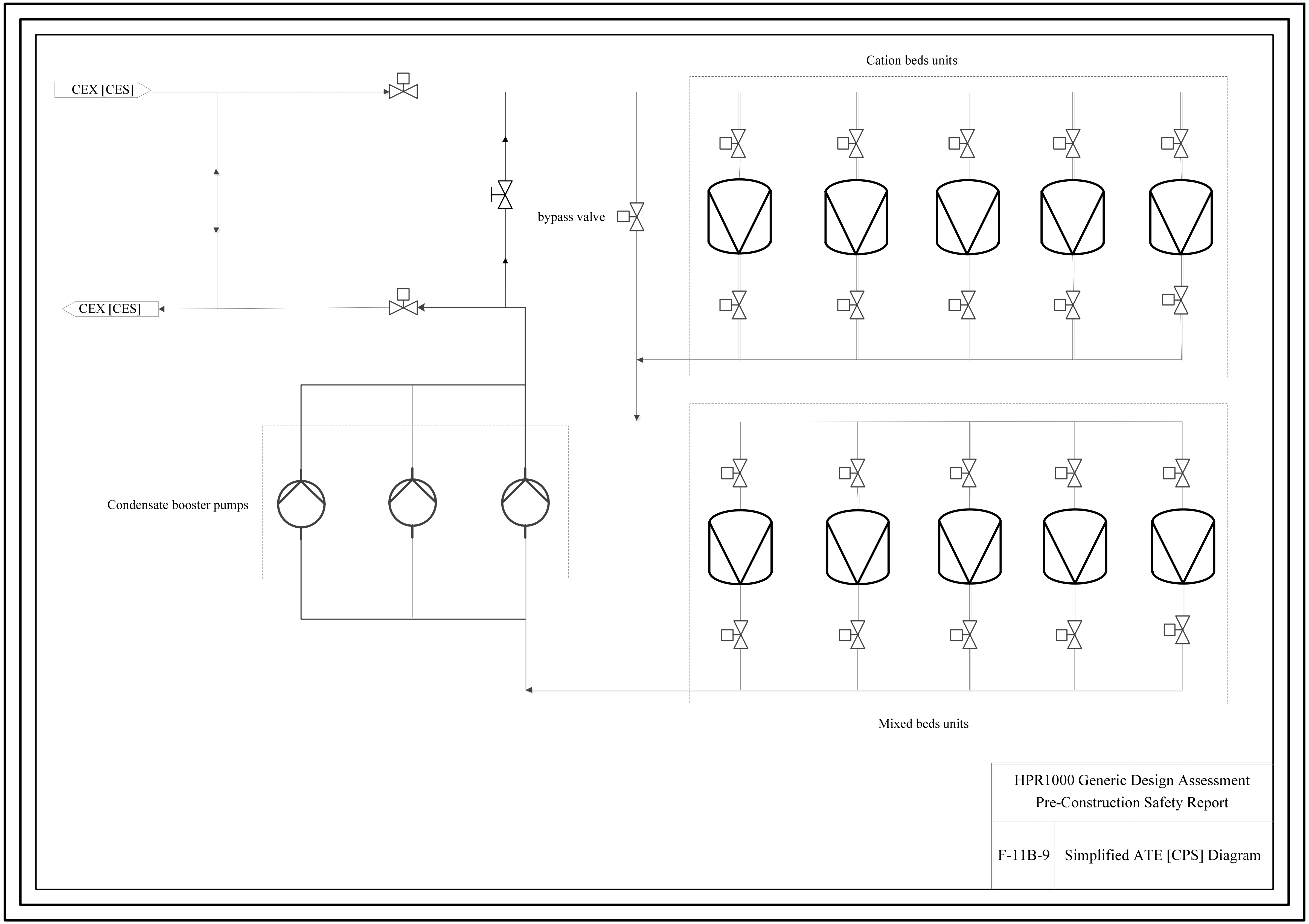
F-11B-6 Simplified Diagram of GCT [TBS]



F-11B-7 Simplified Diagram of ADG [FDTGSS]



F-11B-8 Simplified Diagram of AAD [SSFS]



F-11B-9 Simplified Diagram of ATE [CPS]

Appendix 11C Tables

T-11C-1 Interfaces between Chapter 11 and Other Chapters

PCSR **Chapter**	**Relationship**
Chapter 1 Introduction	Chapter 1 provides the information relevant to the GDA scope, high level safety case route map and the methodology for route map development.
Chapter 2 General Plant Description	Chapter 11 provides a further description of the steam and power conversion system mentioned in Sub-chapter 2.9.
Chapter 4 General Safety and Design Principles	Chapter 4 provides the general safety and design principles including the concept of DiD, safety classification of SSC and engineering substantiation. These principles shall be considered in design, and applicable issues shall be substantiated.
Chapter 6 Reactor Coolant System	Chapter 6 provides supporting functional requirements relevant to safety and operation functions of the RCP [RCS]. Sub-chapter 11.3 provides the design substantiation relevant to these functional requirements.
Chapter 7 Safety Systems	Chapter 7 provides supporting functional requirements relevant to safety and operation functions for safety systems. Sub-chapter 11.3 provides the design substantiation relevant to these functional requirements.
Chapter 8 Instrumentation and Control	Chapter 8 provides design substantiation relevant to these control functions. Sub-chapter 11.3 provides control function requirements that shall be fulfilled by I&C systems.
Chapter 9 Electric Power	Chapter 9 provide the design information relevant to the electrical power systems. Sub-chapter 11.3 provides power supply requirements based on the system function requirement.
Chapter 12 Design Basis Condition Analysis	Chapter 12 provides the justification of the current Sub-chapter 11.3 design in terms of the Design Basis Condition (DBC) analyses. Sub-chapter 11.3 provides the substantiation which takes into consideration the fault analysis.
Chapter 13 Design Extension Conditions and Severe Accident Analysis	Chapter 13 provides the justification of the current Sub-chapter 11.3 design in terms of the Design Extension Condition (DEC) analyses. Sub-chapter 11.3 provides the substantiation which is taken into consideration for the Design Extension Condition analyses.

PCSR Chapter	Relationship
Chapter 14 Probabilistic Safety Assessment	Chapter 14 provides the estimate feedback showing whether potential enhancement areas are present or not. Sub-chapter 11.3 provides the design results for the PSA analysis.
Chapter 15 Human Factors	Chapter 15 provides the principles and methodology of Human Factor Integrity that shall be considered in system and component design. Sub-chapter 11.3 provides the substantiation which is taken into account for further estimates in the human factors assessment.
Chapter 16 Civil Works & Structures	Chapter 16 provides design information relevant to the civil structure. The design result is considered in system and component design such as resistance to the earthquakes.
Chapter 17 Structural Integrity	Chapter 17 provides the structural integrity classification and demonstration of relevant components. Chapter 11 provides the system description of Steam and Power Conversion Systems.
Chapter 18 External Hazards	Chapter 18 provides external hazards relevant to the UK HPR1000 as well as the design principles. Sub-chapter 11.3 provides the substantiation of the system, which is taken into account for further estimates in the hazard schedule.
Chapter 19 Internal Hazards	Chapter 19 provides internal hazards relevant to the UK HPR1000 as well as the design principles. Sub-chapter 11.3 provides the substantiation of the system, which is taken into account for further estimates in the hazard schedule.
Chapter 20 MSQA	Chapter 20 provides the management requirements for the GDA safety case management. Sub-chapter 11.3 shall meet these requirements when producing the safety case.
Chapter 21 Reactor Chemistry	Chapter 21 provides the condensate water chemistry specification for the GDA. Sub-chapter 11.4.8 shall meet these specifications when producing the safety case.
Chapter 22 Radiological Protection	Chapter 22 provides radiological protection design considerations relevant to the steam and power conversion system substantiation. Chapter 11 provides steam and power conversion system design information used in radiological protection design.

PCSR Chapter	Relationship
Chapter 24 Decommissioning	Chapter 24 provides decommissioning design considerations relevant to the SSCs of UK HPR1000. Chapter 11 provides the design substantiation of the principles in Chapter 24.
Chapter 30 Commissioning	Chapter 30 provides arrangement and scope relevant to commissioning. This design information shall be considered in Sub-chapter 11.3.
Chapter 31 Operational Management	Chapter 31 provides the principles and methodology for the periodic tests, inspection, maintenance and ageing and degradation. Sub-chapter 11.3 provides the design substantiation relevant to the periodic test, inspection, maintenance and ageing and degradation.
Chapter 33 ALARP Evaluation	Chapter 33 provides relevant principles, methodology and approach for the ALARP demonstration. Sub-chapter 11.3 provide the ALAPR demonstration for the system based on these principles and the approach.

T-11C-2 Applicable Codes and Standards for UK HPR1000

Codes and Standards	Title
IAEA, No.SSR-2/1 (2016)	Safety of Nuclear Power Plants: Design, IAEA Specific Safety Requirement
IAEA, NO. NS-G 1.9 (2004)	Design of the Reactor Coolant System and Associated Systems in Nuclear Power Plants
RCC-M, 2007 Edition	Design and Construction Rules for Mechanical Components of PWR Nuclear Islands
RSE-M, 2010 edition and 2012 addendum	In-service inspection rules for mechanical components of PWR nuclear islands

T-11C-3 General Parameters of the MSIV

Parameters	Unit	Value
Actuator Type	/	Oleo-pneumatic
Design Pressure	MPa (g)	8.9
Design Temperature	°C	303
Nominal Flow rate	kg/s	586.19
Stroke Time	s	Fast closure: ≤ 5 Slow closure: ≤ 180 Opening: ≤ 360
Material	/	Carbon Steel

T-11C-4 General Parameters of the MSSV

Parameters	Unit	Value
Actuator Type	/	Spring-loaded safety valve
Design Pressure	MPa (g)	8.9
Design Temperature	°C	303
Discharge Mass Flow rate	/	At Least 27% of Nominal Steam Flow Rate at the Design Pressure
Set Pressure	MPa (g)	First MSSV:9.1 Second MSSV:9.3
Material	/	Carbon Steel

T-11C-5 Safety Category of System Function (VVP [MSS])

System Function	Function Category
The isolation of the MSL	FC1
The SG overpressure protection	FC1
Transfer steam from the SG to the ASP [SPHRS]	FC3

T-11C-6 Safety Classification of Main Components (VVP [MSS])

Component	Function Class	Design Provision Category	Design Provision Class	Seismic Class
MSL (Upstream MSIV)	F-SC1	DPM	B-SC2	SSE1
MSIV	F-SC1	DPM	B-SC2	SSE1
MSSV	F-SC1	DPM	B-SC2	SSE1
Bypass Line Isolation Valve	F-SC1	DPM	B-SC2	SSE1

T-11C-7 General Parameters of the FLIV

Parameters	Unit	Value
Actuator Type		Oleo-pneumatic
Design Pressure	MPa (g)	12.9
Design Temperature	°C	250
Nominal Flow rate	kg/s	593
Stroke Time	s	Fast closure: ≤ 5 Slow closure: ≤ 180 Opening: ≤ 360
Material		Carbon Steel

T-11C-8 Safety Category of System Function (ARE [MFFCS])

System Function	Function Category
Main feedwater isolation	FC1
SG and containment isolation	FC1
Steam generator level control	FC3

T-11C-9 Classification for Components (ARE [MFFCS])

Component	Function Class	Design Provision Category	Design Provision Class	Seismic Class
FLIV	F-SC1	NC	NC	SSE1
LLIV	F-SC1	NC	NC	SSE1
MIV	F-SC1	DPM	B-SC2	SSE1
Feedwater Control Valves	F-SC3	NC	NC	SSE2
Feedwater Check Valve	F-SC1	DPM	B-SC2	SSE1

T-11C-10 System Function Classification (APG [SGBS])

System Function	Function Category
SG blowdown isolation and containment isolation	FC1
Water transfer between two SGs	FC1
Secondary water samples isolation	FC2

T-11C-11 Safety Classification of Main Components (APG [SGBS])

Component	Function Class	Design Provision Category	Design Provision Class	Seismic Class
SG blowdown isolation valves	F-SC1	DPM	B-SC2	SSE1
Transfer line valves	F-SC1	DPM	B-SC2	SSE1
Sampling isolation valves	F-SC2	DPM	B-SC2	SSE1