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UK ABWR

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UK ABWR Generic Design Assessment

Generic PCSR Sub-chapter 18.3 : Off-Gas Radioactive Waste Management System

Hitachi-GE Nuclear Energy, Ltd.

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18.3.1 Overview

The Off-gas System (OG) takes gas arising from the main condenser (containing radioactive noble gases and radiolytic hydrogen and oxygen), processes it to reduce its activity and controls the release of the resulting gas to the site environment. Its operation maintains the exposure of individuals at a level that is As Low As Reasonably Practicable (ALARP). The OG process equipment is located within the Turbine Building to minimise the length of piping needed to carry the gas from the main condenser, and housed in a reinforced-concrete structure to provide adequate shielding. The OG Charcoal Adsorbers are installed in a temperature-controlled room to maintain the capability of the charcoal components of the adsorber. [Ref-1][Ref-3][Ref-4][Ref-9][Ref-11]

The OG reduces the possibility of the radiolytic hydrogen and oxygen contained in the off-gas from reacting and causing an explosion. This is accomplished by the catalytic recombination of the radiolytic hydrogen and oxygen in an OG Recombiner within the system. The moisture in the off-gas is condensed to reduce the volume of off-gas within the OG Condenser. The remaining non-condensables (principally air with a slight amount of radioactive substances) are passed through Off-gas charcoal adsorbers, which provide adequate holdup volume across activated charcoal beds to allow time for the radioactive substances to decay to lower activity levels. After processing, the gaseous waste (whose activity is now reduced to a permitted level) is monitored and released to the environment through the stack. [Ref-1][Ref-3][Ref-4][Ref-9][Ref-11]

Source term for OG normal operation and fault condition is described in PCSR Sub-chapter 18.1 “Source Terms, GA91-9101-0101-18001”.

18.3.2 Design Basis

18.3.2.1 Safety Requirement

This section summarises the safety requirements for the OG for the UK ABWR design.

(1) The OG minimises the release of gaseous radioactive substances generated by plant operation into the environment.

(2) The OG reduces the adverse effects on a plant and plant operators caused by the hydrogen combustion or explosion of radiolytic hydrogen produced in the reactor.

(3) The OG extracts air and non-condensable gas (H_2 and O_2) from the Condenser.

(4) Adequate radiation protection measures are provided to ensure that dose to plant operators are reduced. Radiation protection features are addressed in the PCSR Sub-chapter 20.4 “Protection and Provisions against Direct Radiation, GA91-9101-0101-20004”.

18.3.2.2 Safety Function

The OG has been designed to meet the following Safety Function Claims (SFCs). The relation between the SFCs put on this system and the high level claims are shown in Appendix-1.

Normal Operations

(1) The OG minimises the release of radioactive noble gases and iodine to the environment during the startup, power and shutdown operations. This is achieved by ensuring that the activated charcoal provides a sufficient holdup time for radioactive decay. [OG_SFC_4-11.1]
This function is classified as Category C and the components to deliver it are designed to meet Class 3 requirements. [Ref-13]

(2) Part of OG forms the system components boundary which confines the radioactive substances to prevent leakage from the system components. [OG_SFC_4-11.2]
This function of OG Charcoal Adsorber is classified as Category B and the components to deliver it are designed to meet Class 2 requirements. This function of other OG components is classified as Category C and the components to deriver it are designed to meet Class 3 requirements. [Ref-13]

(3) The OG reduces the risk of hydrogen combustion arising from the reaction of radiolytic hydrogen produced in the reactor. This is achieved by providing hydrogen recombining and supplying driving steam to the 2nd stage SJAE.[OG_SFC_4-11.3]
This function is classified as Category C and the components to deliver it are designed to meet Class 3 requirements. [Ref-13]

(4) Radiation level of off-gas is measured to detect deviation from the predicted range (e.g. degradation of the activated charcoal), in addition to monitor at the final discharge line (main stack) to the environment.[OG_SFC_4-11.4]
This function is classified as Category C and the components to deliver it are designed to meet Class 3 requirements. [Ref-13]

(5) The OG extracts air and non-condensable gas (H_2 and O_2) from the Condenser to achieve and maintain condenser vacuum. This is achieved by Steam Jet Air Ejector (SJAE) and associated downstream components, piping and valves.[OG_SFC_5-10.1]
This function is classified as Category B and the components to deliver it are designed to meet Class 3 requirements. [Ref-13]

Fault Conditions

(1) The OG mitigates the release of gaseous radioactive substances to the environment by OG isolation valve closure in case of a fault (e.g. pipe rupture) upon detecting high radiation level at OG component area. [OG_SFC_4-8.1]

This function is classified as Category B and the components to deliver it are designed to meet Class 2 requirements. [Ref-13]

(2) The OG prevents hydrogen explosion by OG isolation valve closure in case of a fault (e.g. performance degradation of OG Recombiner) upon detecting an approach to the lower flammable limit of hydrogen at OG Recombiner outlet line. [OG_SFC_4-11.5]
This function is classified as Category B and the components to deliver it are designed to meet Class 2 requirements. [Ref-13]

(3) The OG process components on the upstream of the OG Condenser Outlet Valve withstand the pressure increase caused by hydrogen explosion. [OG_SFC_4-11.6]
This function is classified as Category C and the components to deliver it are designed to meet Class 3 requirements. [Ref-13]

18.3.3 System Description

This section describes the design of the OG to support and justify the delivery of OG_SFC_-.1, OG_SFC_4-11.1, OG_SFC_4-11.2, OG_SFC_-.2, OG_SFC_5-10.1, OG_SFC_4-8.1, OG_SFC_4-11.3 and OG_SFC_4-11.4.

18.3.3.1 Mode of Operation

The OG is designed to perform the safety functions during the following operation modes.

18.3.3.1.1 Startup operation mode

18.3.3.1.1.1 Startup operation mode (Mode I)

The Reactor is isolated by the Main Steam Isolation Valves (MSIVs) during the Mode I. The Mechanical Vacuum Pump (MVP) is started up to eject the air to a certain degree of vacuum in the Condenser to the Stack. There is no inflow of the gaseous radioactivity and hydrogen gas to the Condenser from the Reactor during Mode I.
Figure 18.3-1 illustrates the OG configuration for this mode of operation.

18.3.3.1.1.2 Startup operation mode (Mode II)

The Reactor is isolated by the MSIVs during Mode II. After reaching a certain degree of vacuum in the Condenser, the Start-up SJAE driven by the Heating Steam System (HS) is started up. The MVP and Start-up SJAE are operated in series during the Mode II. There is no inflow of the gaseous radioactivity and hydrogen gas to the Condenser from the Reactor during Mode II.
Figure 18.3-2 illustrates the OG configuration for this mode of operation.

18.3.3.1.1.3 Startup operation mode (Mode III)

After reaching a certain degree of vacuum in the Condenser, the MVP is shut down. After that the Reactor is connected to the Condenser by opening the MSIVs to perform the deaeration of the Reactor, and started up by withdrawing the Control Rods. The Start-up SJAE continues operation to increase the vacuum in the Condenser. The gaseous radioactivity, hydrogen and oxygen gas generated in the Reactor are treated by the OG process components such as the OG Recombiner and the OG Charcoal Adsorbers.
Figure 18.3-3 illustrates the OG configuration for this mode of operation.

18.3.3.1.2 Power operation mode (Mode IV)

After reaching a certain degree of reactor pressure, the Start-up SJAE operation is taken over to the SJAE driven by main steam. The gaseous radioactivity, hydrogen and oxygen gas generated in the Reactor are treated by the OG process components such as the OG Recombiner and the OG Charcoal Adsorbers.
Figure 18.3-4 illustrates the OG configuration for this mode of operation.

18.3.3.1.3 Shutdown operation mode (Mode V)

The reactor power is decreased and the Reactor is shut down by inserting Control Rods. The function of the SJAE is taken over by the Start-up SJAE after the reactor pressure is decreased to a specified value. After the Reactor shutdown, the remaining gaseous radioactivity, hydrogen and oxygen gas in the Condenser are treated by the OG process components such as the OG Recombiner and the OG Charcoal Adsorbers.
Figure 18.3-5 illustrates the OG configuration for this mode of operation.

18.3.3.2 Equipment Design

Main Structures, Systems and Components (SSCs) are the following.

18.3.3.2.1 SJAE

(1) Purpose

The purpose of SJAE is to extract air that leaks into the Condenser and non-condensable gas (H_2 and O_2) produced by the reactor water radiolysis in normal operation.

(2) Configuration

The SJAE is of a two-stage steam jet type and driven by main steam. The SJAE is connected to the Condenser shell to extract air that leaks into the Condenser and radiolytic hydrogen and oxygen produced in the reactor. The second SJAE is supplied with sufficient steam to maintain the hydrogen concentration downstream at less than 4 percent by volume taking into account steam.

(3) Performance Design

The second SJAE driving steam flow rate is determined so that hydrogen concentration in the off-gas from the SJAE is less than 4 percent by volume taking into account steam.

18.3.3.2.2 Start-up SJAE

(1) Purpose

The purpose of Start-up SJAE is to extract air that leaks into the Condenser during plant startup, and is to extract air and non-condensable gas (H_2 and O_2) produced by the reactor water radiolysis during plant shutdown.

(2) Configuration

The Start-up SJAE is of a two-stage steam jet type and driven by HS. The Start-up SJAE is connected to the Condenser shell to extract air that leaks into the Condenser and radiolytic hydrogen and oxygen produced in the reactor by the SJAE during start-up and shutdown operations. The second Start-up SJAE is supplied with sufficient steam to maintain the hydrogen concentration downstream at less than 4 percent by volume taking into account steam.

(3) Performance Design

The second Start-up SJAE driving steam flow rate is determined so that hydrogen concentration in the off-gas from the Start-up SJAE is less than 4 percent by volume taking into account steam.

18.3.3.2.3 Condenser Air Extraction Valve and SJAE Driving Steam Isolation Valve

(1) Purpose

The first purpose of Condenser Air Extraction Valve and SJAE Driving Steam Isolation Valve is to isolate the condenser extracted gasses manually in case that the radioactive release rate reaches specified set point. The second purpose of them is to isolate the condenser extracted gasses automatically in case that the rupture in the process lines or components in the OG. The third purpose of them is to prevent hydrogen combustion by isolating off-gas inflow automatically in case that hydrogen concentration of OG Recombiner outlet line reaches specified set point.

(2) Configuration

The motor operated Condenser Air Extraction Valves are installed at the outlet of Condenser (A), (B) and (C) respectively. The motor operated SJAE Driving Steam Isolation Valve is installed at the driving steam pressure control valve inlet.

(3) Performance Design

The Main Condenser Outlet Valves and the SJAE Driving Steam Isolation Valve are designed to be closed within appropriate time.

18.3.3.2.4 OG Preheater

(1) Purpose

The purpose of OG Preheater is to heat the off-gas to prevent formation of water drops that might adversely affect catalytic performance of OG Recombiner.

(2) Configuration

One 100 percent-capacity preheater is provided. The capacity is such that the OG Preheater is capable of heating the off-gas above saturated temperature.

(3) Performance Design

The OG Preheater is designed to perform as follows.

(a) Number : 1 unit

(b) Flow rate : Approx. 7,300 m^3/h [normal]

18.3.3.2.5 OG Recombiner

(1) Purpose

The purpose of OG Recombiner is to recombine hydrogen and oxygen in the off-gas below the lower hydrogen flammability limit.

(2) Configuration

Two 100 percent-capacity recombiners are provided. The OG Recombiner recombines hydrogen and oxygen included in the off-gas by catalytic reaction to reduce the possibility of hydrogen and oxygen reacting and causing a hydrogen combustion.

(3) Performance Design

The OG Recombiner is designed to perform as follows.

(a) Number : 2 units

(b) Flow rate : Approx. 7,300 m^3/h [normal]

18.3.3.2.6 OG Condenser

(1) Purpose

The purpose of OG Condenser is to condense steam in the off-gas to reduce the off-gas volume.

(2) Configuration

One 100 percent-capacity condenser is provided. The OG Condenser is designed to condense steam in the off-gas to reduce its volume and to cool the off-gas. The capacity is such that the OG condenser is capable of condensing steam and cooling the off-gas from the temperature at the outlet of the OG Recombiner to nearly room temperature. The cooling source is supplied by the Reactor Building Cooling Water System (RCW).

(3) Performance Design

The OG Condenser is designed to perform as follows.

(a) Number : 1 unit

(b) Flow rate : Approx. 7,100 m^3/h [normal]

18.3.3.2.7 OG Cooler Condenser

(1) Purpose

The purpose of OG Cooler Condenser is to reduce the moisture in the off-gas to ensure the performance of OG Charcoal Adsorber.

(2) Configuration

One 100 percent-capacity condenser is provided. The OG Cooler Condenser cools the off-gas to reduce moisture. The capacity is such that the OG Cooler Condenser is capable of cooling the off-gas to maintain the OG Charcoal Adsorber performance. The cooling source is supplied by the OG Refrigeration Facility.

(3) Performance Design

The OG Cooler Condenser is designed to perform as follows.

(a) Number : 1 unit

(b) Flow rate : Approx. 40 m^3/h [normal]

18.3.3.2.8 OG Charcoal Adsorber

(1) Purpose

The purpose of OG Charcoal Adsorber is to holdup the radioactive noble gases (Xenon and Krypton) and iodine to minimise the radioactive release to the environment.

(2) Configuration

Four 25 percent-capacity charcoal adsorbers are provided in series. The OG Charcoal Adsorber is designed to be capable of holding up the radioactive noble gases in the off-gas for more than 30 days for Xe and more than 40 hours for Kr.

(3) Performance Design

The OG Charcoal Adsorber is designed to perform as follows.

(a)	Number :	4 units
(b)	Flow rate :	Approx. 40 m^3/h [normal]
(c)	Dynamic Adsorption Equilibrium Constant :	
		Xe: Approx. 650 m^3/t
		Kr: Approx. 36 m^3/t
	in the following conditions	
	(i)Pressure:	78 kPa [abs]
	(ii)Temperature:	25 °C
(d)	Quantity of activated carbon :	Approx. 72t

18.3.3.2.9 OG Filter

(1) Purpose

The purpose of OG Filter is to remove solid substances from the off-gas thorough the OG Charcoal Adsorber.

(2) Configuration

One 100 percent-capacity filter is provided. The OG Filter removes solid substances from the off-gas.

(3) Performance Design

The OG Filter is designed to perform as follows.

(a)	Number :	1 unit
(b)	Flow rate :	Approx. 40 m^3/h [normal]

18.3.3.2.10 OG Blower

(1) Purpose

The purpose of OG Blower is to keep the off-gas pressure negative in the OG Charcoal Adsorber and eject the off-gas via the Stack during start-up operation. The OG Blower is available as a backup to the OG Ejector during power operation and shutdown operation.

(2) Configuration

One 100 percent-capacity blower is provided. The OG Blower has sufficient capacity to keep the off-gas at negative pressure in the OG Charcoal Adsorbers, and has sufficient capacity to eject the off-gas via the Stack for the off-gas conditions during start-up operation (80 m^3/h [normal]).

(3) Performance Design

The OG Blower is designed to perform as follows.

(a) Number : 1 unit

(b) Flow rate : Approx. 80 m^3/h [normal]

18.3.3.2.11 OG Ejector

(1) Purpose

The purpose of OG Ejector is to keep the off-gas pressure negative in the OG Charcoal Adsorber and eject the off-gas via the Stack during power operation and shutdown operation.

(2) Configuration

One 100 percent-capacity ejector is provided. The OG Ejector has sufficient capacity to keep the off-gas at negative pressure in the OG Charcoal Adsorbers, and has sufficient capacity to eject the off-gas via the Stack for the off-gas conditions during power operation (40 m^3/h [normal]). The driving air is provided by the Station Service Air System (SA).

(3) Performance Design

The OG Ejector is designed to perform as follows.

(a) Number : 1 unit

(b) Flow rate : Approx. 40 m^3/h [normal]

18.3.3.2.12 OG Charcoal Adsorber Room Heating Ventilating Handling Unit (HVH)

(1) Purpose

The purpose of OG Charcoal Adsorber Room HVH is to control the temperature of the OG Charcoal Adsorber Room to ensure the performance of OG Charcoal Adsorber.

(2) Configuration

Two 100 percent-capacities Heating Ventilating Handling Unit (HVH) are provided (cooling coil, fan and electric heater). The OG Charcoal Adsorber Room HVH controls the OG Charcoal Adsorber Room temperature to maintain the OG Charcoal Adsorber performance. The OG Charcoal Adsorber is designed to be capable of controlling the temperature in the OG Charcoal Adsorber Room within the 25 ± 5°C. The cooling source is provided by HVAC Normal Cooling Water (HNCW) and the heating source is provided by electric heaters.

(3) Performance Design

(a) Number : 2 units

(b) Capacity : Approx. 6,000 m^3/h

18.3.3.2.13 Main Support Systems

The major support systems are briefly described as follows.

18.3.3.2.13.1 Instrumentation and Control

The principal instrumentation and controls related to OG operations are summarised as follows.

(1) Instrumentation

Instrumentation is provided to measure and monitor the operating conditions of the OG components. The major provisions for instrumentation are described as follows.

(a) SJAE driving steam pressure
(b) OG Preheater inlet and outlet temperature
(c) OG Recombiner (A)/(B) inlet and outlet temperature
(d) OG Condenser water level and outlet temperature
(e) OG Cooler Condenser outlet temperature
(f) OG Charcoal Adsorber inlet flow rate, inlet pressure and inlet temperature
(g) OG Ejector inlet pressure and drive air pressure
(h) OG Blower inlet pressure
(i) OG Charcoal Adsorber Room outlet temperature
(j) OG Charcoal Adsorber Room HVH (A)/(B) inlet temperature
(k) OG Recombiner outlet hydrogen concentration
(l) OG component area radiation level

(2) Controls

The main controls for OG operations are summarised as follows.

(a) Start-up SJAE

The driving steam of Start-up SJAE is controlled by a pressure control valve installed at the driving steam line to reduce the steam pressure to the required.

(b) SJAE

The driving steam of SJAE is controlled by pressure control valve installed at the driving steam line to reduce the steam pressure to the required.

(c) OG Preheater

The OG Preheater automatically controls the off-gas temperature at the outlet of the OG Preheater by controlling the HS flow rate.

(d) OG Ejector

The recirculation flow rate in the OG Ejector recirculation line is automatically controlled to hold constant the OG Ejector suction pressure.

(e) OG Blower

The recirculation flow rate in the OG Blower recirculation line is automatically controlled to hold constant the OG Blower suction pressure. The OG Blower automatically starts in the case of the OG Ejector trip.

(f) OG Charcoal Adsorber Room HVH

The OG Charcoal Adsorber Room temperature is controlled within the determined ranges (25 ± 5 ℃) by the OG Charcoal Adsorber Room HVH Cooling Coil or the OG Charcoal Adsorber Room HVH Electric Heater.

18.3.3.2.13.2 Power Supply System

The OG components are basically connected to the normal power supply except for the Condenser Air Extraction Valves and SJAE Driving Steam Isolation Valve.

18.3.3.2.13.3 Reactor Building Cooling Water System (RCW)

The RCW supplies cooling water to OG Condenser and the OG Refrigerator Facility.

18.3.3.2.13.4 Heating Steam System (HS)

The HS supplies heating steam to OG Preheater. The HS also supplies heating steam to the Start-up SJAE.

18.3.3.2.13.5 Station Service Air System (SA)

The SA supplies air for driving the OG Ejector.

18.3.3.2.13.6 Turbine Auxiliary Steam System (AS)

The Turbine Auxiliary Steam System (AS) supplies heating steam to the SJAE.

18.3.3.2.13.7 HVAC Normal Cooling Water System (HNCW)

The HNCW supplies cooling water for the OG Charcoal Adsorber Room HVH.

18.3.4 Safety Assessment

This section describes radioactive release evaluation.

18.3.4.1 Normal Operation

Dose evaluation during the normal operation is carried out. The calculated dose exposures are addressed in “Prospective Dose Modelling” [Ref-2].

18.3.4.2 Fault Condition

Dose evaluation in the event of a fault is carried out. The calculated dose exposures are addressed in the Generic PCSR Chapter 24 “Design Basis Analysis, GA91-9101-0101-24000”.

18.3.4.3 ALARP Assessment

This section describes the ALARP case for the OG. Under normal operations the OG ensures that the risks posed by gaseous radioactive waste and hydrogen entrained, abated and ultimately discharged from the OG are ALARP. The OG also comprises those measures required to reduce the risks in the event of a fault to the OG.

Under normal operations the OG is in place to manage the following risks;

- Release of radioactive substances,
- Hydrogen combustion, and
- Dose to workers from the radioactive substances.

A fault in the OG has the potential to present a risk. The significant risks have been identified by the FMEA work [Ref-14] and include;

- Rupture in the process lines or components in the OG,
- Degradation of charcoal performance,
- Unexpected open and close of the valves in the OG, and
- Blockage of the component in the OG

An ALARP assessment of the OG system has been developed coupled with semi-quantitative risk assessment methodology as documented in [Ref-15]. The hazards that are considered to dominate the risks from the OG system both during normal operation and under plant fault conditions are radiation from short lived radionuclides and deflagration.

Following risk assessment of the full set of scenarios identified, and where the risks are found to fall within the 'Tolerable if ALARP' region, additional risk reduction measures that could be implemented to minimise the likelihood and/or reduce the extent of harm are identified through ALARP review. When identifying risk reduction measures, the hierarchy of Prevention, Protection and Mitigation is applied in this order of preference. The proportionality of the risk reduction measures is then assessed based on the ALARP assessment methodology, which is fully compliant with ONR's Technical Assessment Guide on ALARP [Ref-3].

The options assessment carried out as part of an ALARP review has identified risk reduction measures that could be implemented to further reduce the risks associated with the UK ABWR. A selection of these are presented below for reference. The risk reduction that would be achieved was also quantified and the residual risks documented. However, as described in [Ref-15], work is currently ongoing to fully define the design modifications required, estimate their costs (qualitatively), validate the residual risk scores as well as assess the risks throughout the lifecycle of the plant (to include decommissioning activities). It has been proposed that the following risk reduction measures are assessed:

- The OG mitigates the release of radioactive noble gases to the environment during normal operation. This is achieved by delaying the release of short lived radionuclides using activated charcoal delay beds which is designed to be capable of suitably holding up the radioactive noble gases in the OG so that discharge of the radioactivity is reduced ALARP.

- The OG includes a SJAE which ensures that any hydrogen extracted from the condenser with other incondensable gases is diluted using steam below flammable limits. The OG uses catalytic recombiners to remove hydrogen before the driving steam is condensed to minimise the risk of hydrogen explosion.

- The design of UK ABWR includes measures to minimise direct doses during each operational stage to ensure that dose to operators is reduced to ALARP Radiation protection features are discussed in more detail in PCSR Sub-chapter 20.4 “Protection and Provisions against Direct Radiation, GA91-9101-0101-20004”. These measures include restricting worker access, isolating the charcoal bed in the event of a loss of containment and providing shielding.

Additional hazardous scenarios may be defined as part of OG system HAZOP, and these will then be subject to risk assessment and ALARP review as per [Ref-2]. Further design modifications /risk reduction measures may then be identified, assessed and taken forward for implementation. As per [Ref-2], all reasonably practicable measures will be implemented and the ALARP review cycle continued through the lifetime of the installation so that the risks continue to be ALARP not only at the design stage but also during operation through to decommissioning.

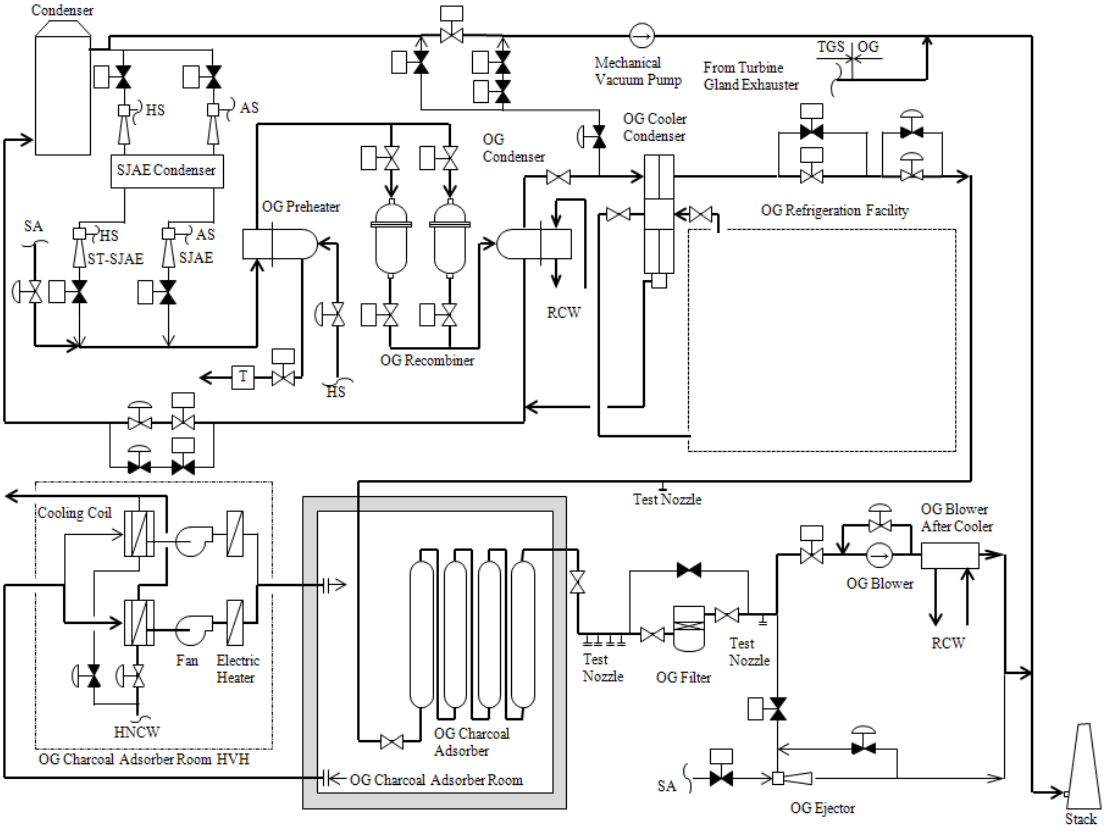

Figure 18.3-1 : Outline of the Startup Operation Mode I

[Ref-5][Ref-6][Ref-7][Ref-8][Ref-10][Ref-12]

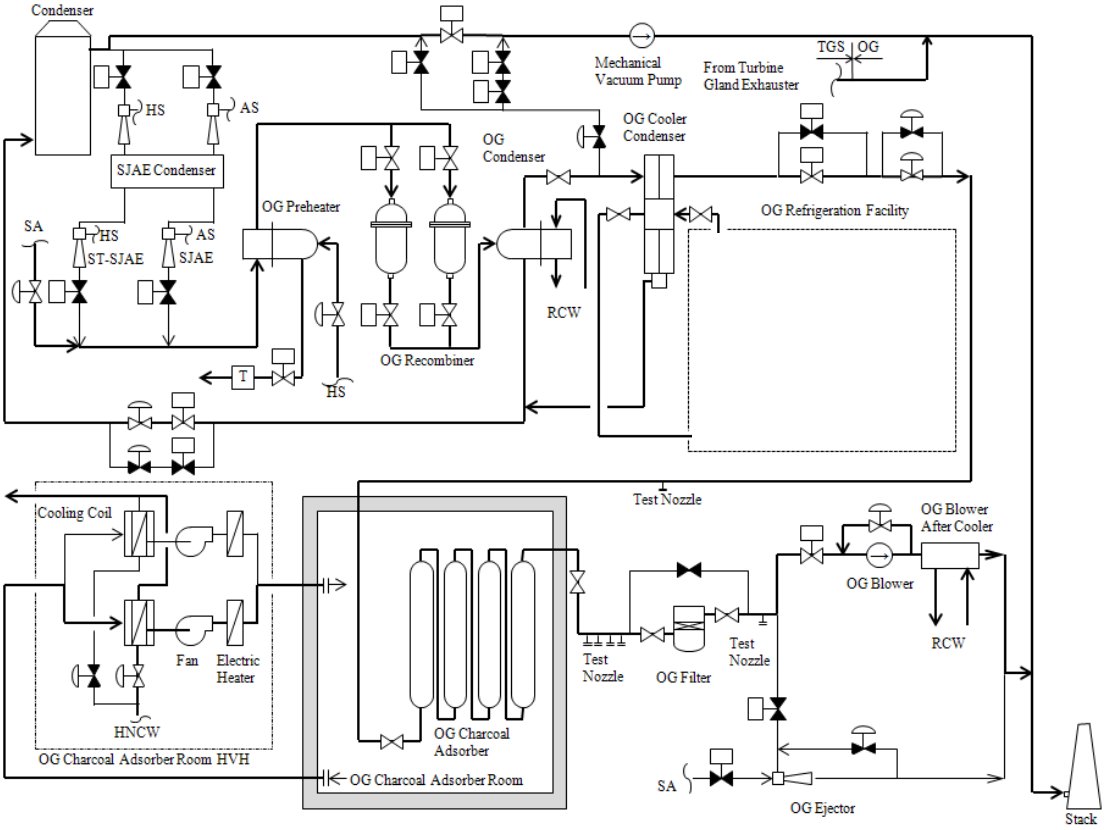

Figure 18.3-2 : Outline of the Startup Operation Mode II

[Ref-5][Ref-6][Ref-7][Ref-8][Ref-10][Ref-12]

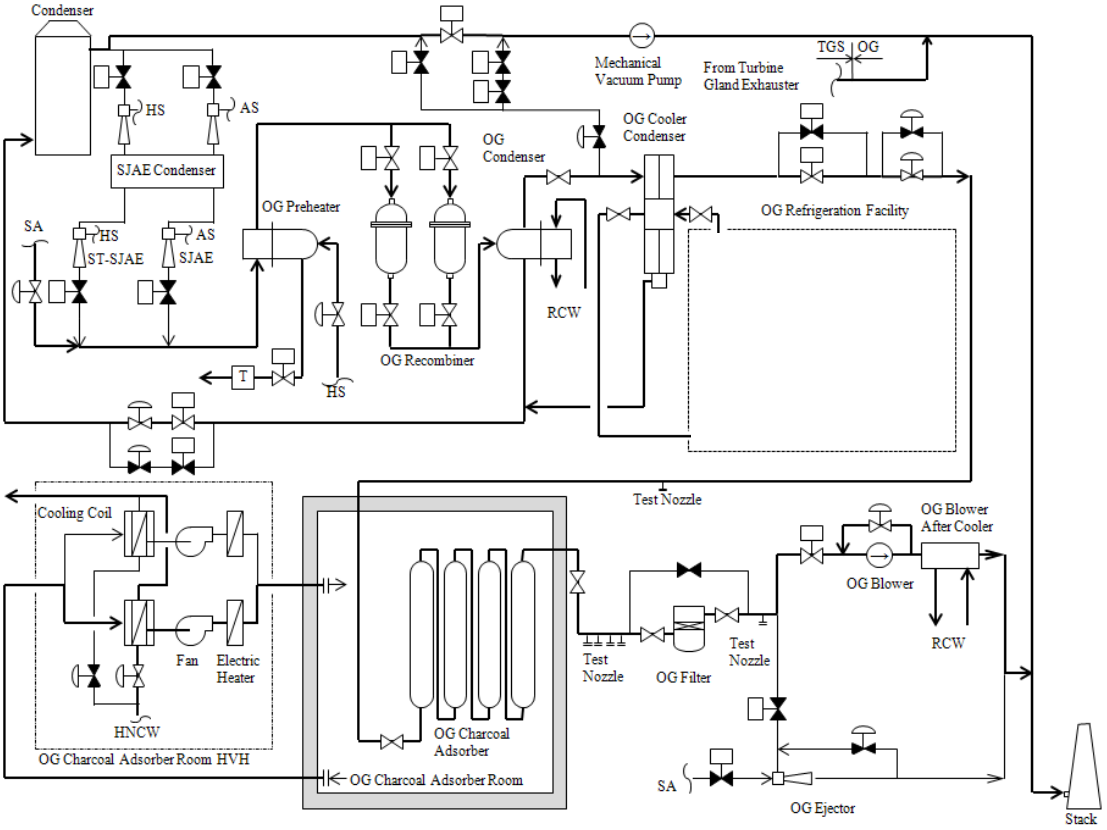

Figure 18.3-3 : Outline of the Startup Operation Mode III

[Ref-5][Ref-6][Ref-7][Ref-8][Ref-10][Ref-12]

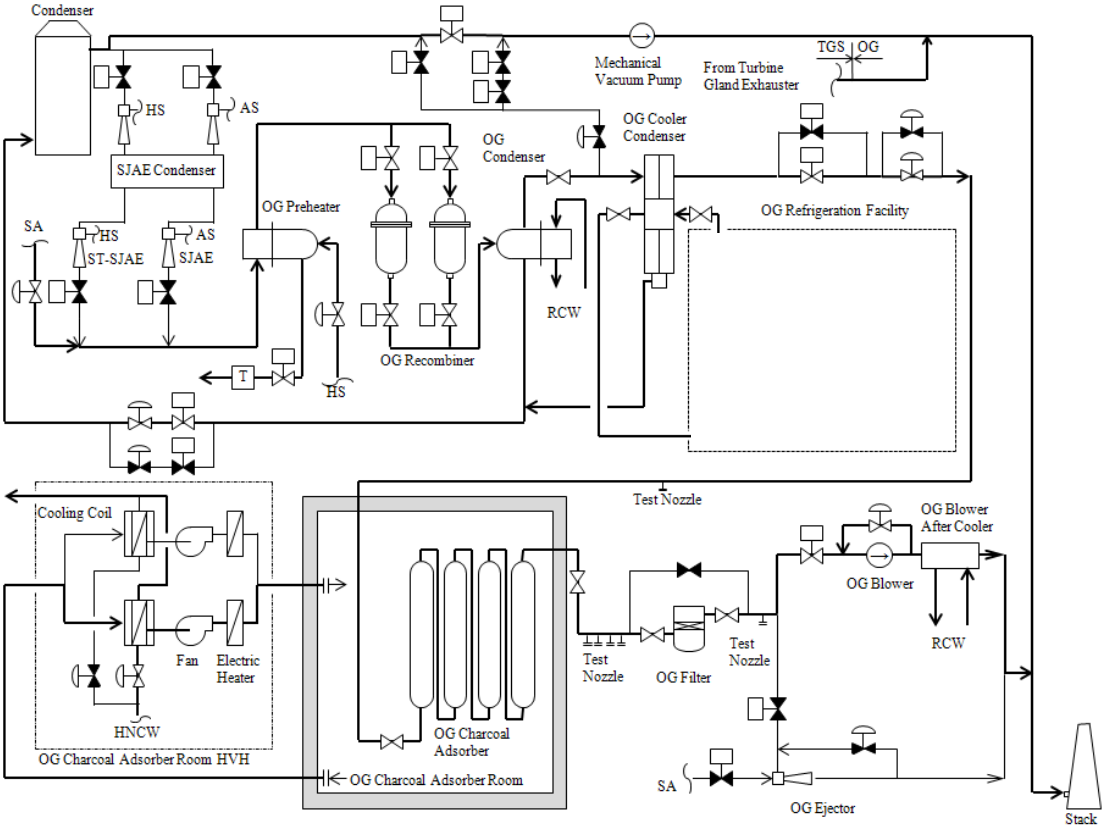

Figure 18.3-4 : Outline of the Power Operation Mode IV

[Ref-5][Ref-6][Ref-7][Ref-8][Ref-10][Ref-12]

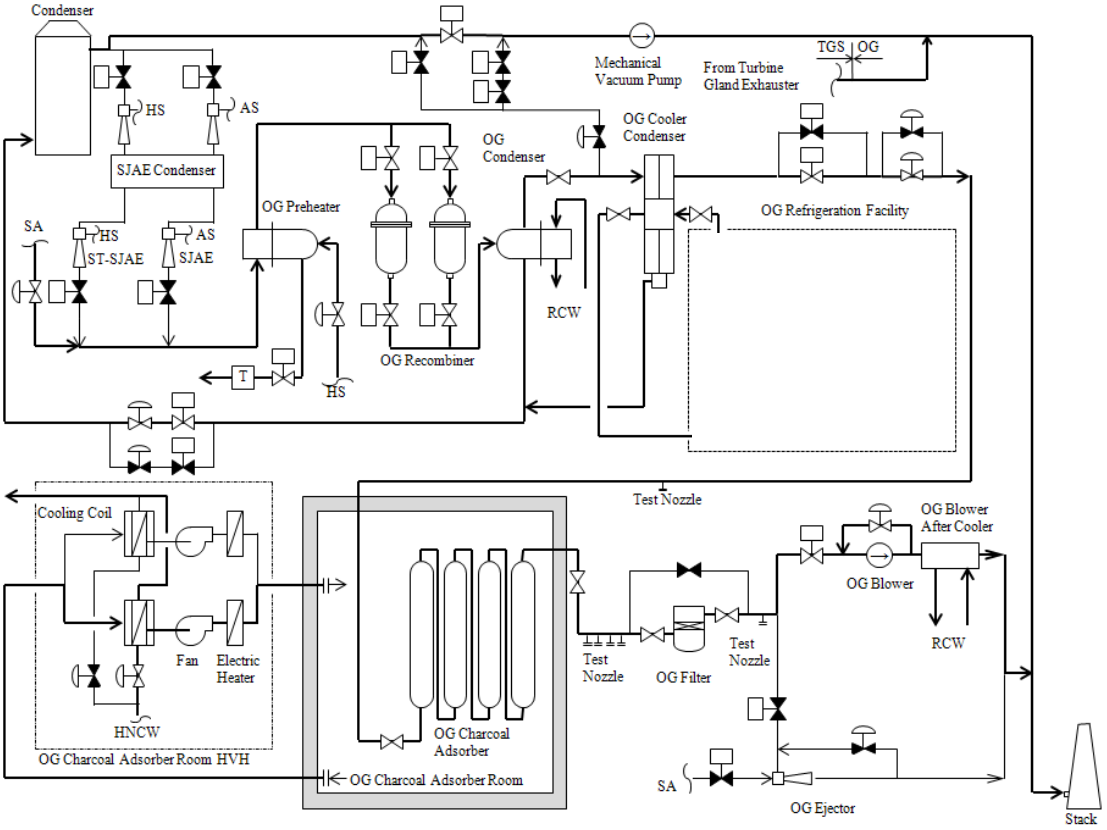

Figure 18.3-5 : Outline of the Shutdown Operation Mode V

[Ref-5][Ref-6][Ref-7][Ref-8][Ref-10][Ref-12]

18.3.5 References

[Ref-1] Hitachi-GE Nuclear Energy, Ltd., "Demonstration of BAT", GA91-9901-0023-00001 (XE-GD-0097) Rev. D, 28-Nov.-2014

[Ref-2] Hitachi-GE Nuclear Energy, Ltd., "Prospective Dose Modelling", GA91-9901-0026-00001 (HE-GD-0005) Rev. D, 06-Aug.-2014

[Ref-3] Hitachi-GE Nuclear Energy, Ltd., "Off-Gas System Basis of Safety Case", GA91-9201-0002-00054 (GE-GD-0009) Rev. 2, 27-Apr.-2015

[Ref-4] Hitachi-GE Nuclear Energy, Ltd., "Off-Gas System System Design Description", GN62-1001-0001-00001 (GD-GD-0001) Rev. 0, 15-Jul.-2013

[Ref-5] Hitachi-GE Nuclear Energy, Ltd., "Off-Gas System P&ID (1/4)", GN62-2101-0001-00001 (310PB35-971) Rev. 0, 6-Mar.-2014

[Ref-6] Hitachi-GE Nuclear Energy, Ltd., "Off-Gas System P&ID (2/4)", GN62-2101-0001-00002 (310QC98-327) Rev. 0, 6-Mar.-2014

[Ref-7] Hitachi-GE Nuclear Energy, Ltd., "Off-Gas System P&ID (3/4)", GN62-2101-0001-00003 (310QC98-328) Rev. 0, 6-Mar.-2014

[Ref-8] Hitachi-GE Nuclear Energy, Ltd., "Off-Gas System P&ID (4/4)", GN62-2101-0001-00004 (310QC98-329) Rev. 0, 6-Mar.-2014

[Ref-9] Hitachi-GE Nuclear Energy, Ltd., "Turbine Main Steam & Turbine Auxiliary Steam & Turbine Bypass System System Design Description", GN11-1001-0001-00001 (SBD-GD-0001) Rev. 1, 23-Jul.-2015

[Ref-10] Hitachi-GE Nuclear Energy, Ltd., "Turbine Auxiliary Steam System P&ID (1/2)", GN39-2101-0001-00001 (310QD02-018) Rev. 0, 10-Feb.-2014

[Ref-11] Hitachi-GE Nuclear Energy, Ltd., "Air Off Take System System Design Description", GN21-1001-0002-00001 (SBD-GD-0003) Rev.1, 23-Jul.-2015

[Ref-12] Hitachi-GE Nuclear Energy, Ltd., "Air Off Take System P&ID", GN21-2101-0002-00001 (310QD02-004) Rev. 0, 10-Feb.-2014

[Ref-13] Hitachi-GE Nuclear Energy, Ltd., "List of Safety Category and Class for UK ABWR", GA91-9201-0003-00266 (AE-GD-0224) Rev.1, 26-Jun.-2015

[Ref-14] Hitachi-GE Nuclear Energy, Ltd., "Topic Report on Fault Assessment", GA91-9201-0001-00022 (UE-GD-0071) Rev. 2, 1-May-2015

[Ref-15] Hitachi-GE Nuclear Energy, Ltd., "Topic Report on ALARP Assessment for Off-Gas System", GA91-9201-0001-00125 (GE-GD-0035) Rev. 1, 28-May-2015

18.3.6 Appendix

Appendix-1: Claim tree for Ch. 18.3 (OG)

Appendix-1: Claim tree for Ch. 18.3 (OG)

	Top Claim for mechanical system						Others (Corresponding source of claim)	Safety Functional Claim (SFC) for the mechanical system and components		
	Fundamental Safety Function (FSF)		High Level Safety Function (HLSF)		Fault Schedule (Bounding Fault)			State	Claim ID	Claim Contents
	PCSR Ch.5.4 (List of Safety Category and Class for UK ABWR (AE-GD-0224) 3.2 Identification of ABWR Safety Functions)		PCSR Ch.5.4 (List of Safety Category and Class for UK ABWR (AE-GD-0224) 3.6 Summary of Safety Category and Classification)		Topic Report on Fault Assessment (UE-GD-0071) Table.4.2-1 Fault Schedule					
1	4	Confinement / Containment of radioactive materials	4-11	Functions to store the radioactive materials as gaseous waste	-	No Claim	GEP Demonstration of BAT (XE-GD-0097) Claim 2 - Minimise the Radioactivity in Radioactive Waste Disposed to the Environment	Normal Operations	OG_SFC_4-11.1	The OG minimises the release of radioactive noble gases and iodine to the environment during the startup, commercial and shutdown operations. This is achieved by ensuring that the activated charcoal provides a sufficient hold up time for radioactive decay.
2	4	Confinement / Containment of radioactive materials	4-11	Functions to store the radioactive materials as gaseous waste	-	No Claim	-	Normal Operations	OG_SFC_4-11.2	Part of OG forms the system components boundary which confines the radioactive substances to prevent leakage from the system components.
3	4	Confinement / Containment of radioactive materials	4-11	Functions to store the radioactive materials as gaseous waste	-	No Claim	-	Normal Operations	OG_SFC_4-11.3	The OG reduces the risk of hydrogen combustion arising from the reaction of radiolytic hydrogen produced in the reactor. This is achieved by providing hydrogen recombines and supplying driving steam to the 2nd stage SJAE.
4	4	Confinement / Containment of radioactive materials	4-11	Functions to store the radioactive materials as gaseous waste	-	No Claim	GEP Approach to Sampling and Monitoring (3E-GD-K002) Claim 3 – Minimisation of Radioactive Discharge	Normal Operations	OG_SFC_4-11.4	Radiation level of off-gas is measured to detect deviation from the predicted range (e.g. degradation of the activated charcoal), in addition to monitor at the final discharge line (main stack) to the environment.
5	5	Others	5-10	Functions to supply electric power (except for emergency supply)	-	No Claim	-	Normal Operations	OG_SFC_5-10.1	The OG extracts air and non-condensable gas (H2 and O2) from the Condenser to achieve and maintain condenser vacuum. This is achieved by Steam Jet Air Ejector (SJAE) and associated downstream components, piping and valves.
6	4	Confinement / Containment of radioactive materials	4-8	Functions to minimise the release of radioactive gases	12.1	Offgas treatment system failure	-	Fault Scenarios	OG_SFC_4-8.1	The OG mitigates the release of gaseous radioactive substances to the environment by OG isolation valve closure in case of a fault (e.g. pipe rupture) upon detecting high radiation level at OG component area.
7	4	Confinement / Containment of radioactive materials	4-11	Functions to store the radioactive materials as gaseous waste	-	No Claim	-	Fault Scenarios	OG_SFC_4-11.5	The OG prevents hydrogen explosion by OG isolation valve closure in case of a fault (e.g. performance degradation of OG recombiner) upon detecting an approach to the lower flammable limit of hydrogen at OG recombiner outlet line.
8	4	Confinement / Containment of radioactive material	4-11	Functions to store the radioactive materials as gaseous waste	-	No Claim	-	Fault Scenarios	OG_SFC_4-11.6	The OG process components on the upstream of the OG Condenser Outlet Valve withstand the pressure increase caused by hydrogen explosion.