EUROPEAN COMMISSION
5th EURATOM FRAMEWORK PROGRAMME 1998-2002
KEY ACTION : NUCLEAR FISSION

HTR-E

High-Temperature Reactor Components and Systems

CONTRACT N°
FIKI-CT-2001-00177

HTR-E WP6 Helium Purification System
Helium environment of HTTR and HTR 10

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FRAMATOME ANP

FRANCE

Dissemination level : RE
Document N°: HTR-E-02/09-D-6-1-1
Status : Preliminary

FRAMATOME ANP

NOVATOME

NUMERO D'OTP OU EOTP	NOMBRE DE PAGES : 30	RAISON SOCIALE FOURNISSEUR :	
	NOMBRE D'ANNEXES : 0		
12T.DTHTREW6NV	CONFIDENTIALITE : N	NUMERO DE COMMANDE	IMMATRICULATION FOURNISSEUR

CODE		DESIGNATION
AFFAIRE	HT	**HTR**
NATURE	DT	**Note technique**
THEME		
MATERIEL		

TITRE : **HTR-E WP6 - Helium environment of HTTR and HTR10**

TITRE ABREGE : **HTR-E WP6 - HELIUM ENVIRONMENT OF HTTR AND HTR10**

IND	DATE	ETAT	REDACTEUR NOM-VISA	VERIFICATEUR NOM-VISA	APPROBATEUR NOM-VISA	MODIFICATIONS – OBSERVATIONS – ACCORDS REFERENCES ET DATES
A	26/09/2002	DES	F. Cellier	P. Guillermier	J. Roleau	First issue

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IMMATRICULATION CLIENT : **HTR-E 02/09-D-6-1-1**

IMMATRICULATION INTERNE : EVEK | DC | 02 | 0390 | ELR / (UNITE | TYPE | ANNEE | CHRONO | TRIGRAMMES)

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Modifications

Revision	Date	Modifications
A	26/09/2002	First issue

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Summary

This document contributes to HTR-E project WP6 (helium purification system) of the 5th European FWP. It is a state-of-the-art report on the He purification system of the Japanese HTTR and Chinese HTR-10 test reactors.

Information on helium specifications, purification system design and helium atmosphere in reactors during operation are provided.

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1. INTRODUCTION

This document contributes to HTR-E project WP6 (helium purification system) of the 5th European FWP. It aims to collect all available literature and data on helium quality and purification systems in Japanese HTTR and Chinese HTR-10 reactors.

These test reactors are currently under active development and represent 2 designs for modular high temperature gas reactors : the HTTR design employs prismatic fuel (hexagonal blocks ~ 35 cm wide by 75 cm high) while the HTR-10 design employs pebble fuel (6 cm diameter spheres).

The normal sources of contaminants in HTR helium coolant are those which are desorbed from reactor components, residual air and air in-leakage, fission products that migrate from the fuel, moisture from steam generator leakage and contaminants from new helium supply.

The function of Helium Purification System (HPS) is to provide the required helium purity in the coolant circuit. Dusts and particles, gaseous chemical impurities and radio-nuclide fission products have to be continuously removed and monitored.

HPS is also used to detect a water ingress in the primary circuit due to failure of exchange tubes.

In each case after a brief description of the reactor and its cooling system, we give the results of our investigations about its helium environment and purification system.

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2. High Temperature Engineering Test Reactor (HTTR)

2.1 Introduction

The High Temperature Engineering Test Reactor (HTTR) have been constructed by the Japan Atomic Energy Research Institute (JAERI). It is well described in [1].

JAERI started reactor construction in March 1991, approximately completed the reactor in July 1998, and accomplished the first criticality in November 1998.

The prismatic core has a thermal output of 30MWth, a rated outlet coolant temperature of 850 °C (rated operation mode) and can raise the gas temperature up to 950°C (high temperature test operation mode).

HTTR is used for basic research on high temperature engineering with the aim of establishing and upgrading the high-temperature gas-cooled reactors technologies, and demonstrating the possibility of industrially utilising the 900 °C heated high-temperature helium gas to produce hydrogen from natural gas and water.

Along with the HTTR, Japan has developed other test facilities such as the Helium Engineering Demonstration loop (HENDEL). HENDEL is designed for performing demonstration tests of core components, reactor internals, and high temperature components in the HTTR.

HENDEL provides the same conditions for the helium gas regarding temperature, pressure and flow rate as in the HTTR. Full scale models of components are tested in the in core structure test section which is a full scale model of the core bottom structure of the HTTR. Heat transfer and flow characteristics of fuel elements are tested in the fuel stack test section.

2.2 Reactor cooling system

The Reactor Cooling System of the HTTR is composed of a Main Cooling System (MCS), an Auxiliary Cooling System (ACS) and a Vessel Cooling System (VCS). The flow diagram of the HTTR cooling system is depicted schematically in figure 1.

Under the normal condition, the MCS removes the heat of 30 MW generated in the reactor core and release it to the atmosphere through air coolers. It consists of a Primary Cooling System (PCS), a Secondary Helium Cooling System (SCHS) and a Pressurised Water Cooling System (PWCS).

The MCS incorporate a helium-helium, Intermediate Heat Exchanger (IHX), a Primary Pressurised Water Cooler (PPWC), a Secondary Pressurised Water Cooler (SPWC) and pressurised water / air cooler.

Note that the IHX is equipped to supply high temperature clean helium for process heat application systems. That why the MCS has two operation modes :

– a single loaded operation in which the reactor is cooled only by the PPWC of 30MW ;

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– a parallel loaded operation in which the IHX and the PPWC remove 10 and 20 MW of heat, respectively.

The SPWC serves the function of removing the heat from the IHX. The air cooler cools the pressurised water for both the PPWC and the SPWC, and releases the heat of 30MW from the reactor core in the air.

The ACS is initiated in case of a reactor scram, if the core cooling by a forced circulation is possible while the MCS is stopped. It consists mainly of an auxiliary heat exchanger, 2 auxiliary gas circulators and an auxiliary water cooling system including an air cooler.

The VCS is used to adjust the amount of heat removal during the normal operation to accomplish the outlet gas temperature of 950 °C and as a residual heat removal system when the forced circulation can not be maintained in the PCS. It consists of upper, lower and side cooling panels, heat removal adjustment panels around the reactor pressure vessel and cooling water circulation systems.

2.3 He purification system

2.3.1 Preamble

In the HTTR design the Helium Purification System (HPS) is located in a service area surrounding the containment vessel. An HPS is installed for the PCS and another for the SCHS. They are similar and were designed taking account of the experience in the HENDEL (and the OGL-1) facility.

The HPS have to limit impurity concentration to reduce oxidation of graphite structures, to ensure in an hour a ratio of purified helium gas to PCS helium inventory greater than 0,1 and to purge stand pipes.

The specifications for upper limits of impurity concentration in the primary helium are given in table 1 (from [2]).

During the commissioning tests of the HPS, impurity concentration to reach in the PCS were specified; their levels as a function of the primary helium temperature are given in table 2 (from [4]).

The main features of the HTTR helium purification systems are described in [3]. The JAERI report on the commissioning tests of these systems give further technical and procedure-related information [4].

2.3.2 Operation of the HPS

2.3.2.1 Primary helium

A main flow diagram of primary HPS is shown in figure 2. With a throughput of 200 kg/h, the HPS allows a cleansing of 10% of the total primary helium inventory per hour.

During normal operation a small part of the primary He (0,5 % - 200 kg/h) flows through the ACS to the primary HPS so as to remove chemical impurities such as hydrogen, carbon monoxide, water vapour, carbon dioxide, methane, oxygen, nitrogen, etc. and to reduce fuel products in the PCS.

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The HPS for primary helium is composed of a Pre Charcoal Trap (PreCT), an inlet heater, two Copper Oxide fixed Beds (COB), coolers, two Molecular Sieve Traps (MST), two Cold Charcoal Traps (CCT) and gas circulators. Traps are redundant in order to switch from one to the other for regeneration without stopping the purification process.

The primary helium enter the HPS at 80 °C and 3,9 MPa with a flow rate of 197 kg/h. An entrance filter removes dusts (graphite). Then helium enter the PreCT in which radioactive iodine is eliminated by absorption.

Although not shown on the main flow diagram primary helium flows also from the Helium Sampling System (HSS) and from a device called "Fuel Failure Detector" (FFD) into the HPS (from [4]).

Helium from the PreCT is mixed with helium from the HSS and the FFD then heated at 280 °C in the inlet heater of the COB. The helium gas flow in the HPS main circuit (200 kg/h) is measured at the inlet of this heater.

Hydrogen and carbon monoxide are converted to water vapour and carbon dioxide, respectively, in the COB. Helium flowing out of the COB is cooled from 280 °C to 15 °C in the downstream cooler then enter the MST in which water vapour and carbon dioxide are absorbed.

A part (1/4 flow rate) of helium flowing out of the MST is derived to the CCT. The gas is cooled from 15°C to -196°C by liquid nitrogen and is purified at the rate of 50 kg/h by absorption of the noble gases, methane, oxygen and nitrogen in the CCT. Helium from the CCT joins the initial flow (150 kg/h, 15 °C) at the inlet of the gas circulator (filter).

Then purified helium gas returns to the ACS, to stand pipes and to the FFD.

2.3.2.2 Secondary helium

The flow diagram of secondary HPS is almost the same as that for the primary HPS except for the absence of the pre-charcoal trap, and only one CCT at the end of the purification train. COBs and MSTs are always redundant.

Since there is a small quantity of chemical impurities in secondary He gas compared with the primary He gas, the capacity of secondary HPS is smaller than for the primary HPS. It is designed to have a throughput of 10 kg/h [2].

Secondary helium flows from 2 points :

- the cold part of the Secondary Pressurised Water cooler (SPWC), on the discharge side of the secondary helium gas circulator ;
- the secondary Helium Sampling and Analysis System (HSAS).

Note also that the pressure control of secondary He is achieved by the secondary Helium Storage and Supply System (HSSS) through the secondary HPS.

The purification flow rate is 10 kg/h. A filter removes dusts from the SPWC. Filtered helium is mixed with helium from the secondary HSS, and the gas is heated up to 300 °C.

H_2 et CO are oxidised by CuO, then helium is cooled down to 15 °C and enters the MST. H_2O et CO_2 are removed, and the nitrogen cooled CCT finally eliminate CH_4, N_2, O_2 by absorption.

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At the outlet of the CCT helium is heated up to 5 °C by a heat exchanger. Helium pressure is increased by the gas circulator and helium temperature is set to 320 °C by a heater.

Purified He returns to the cold part of the SPWC (on the suction side of the secondary helium gas circulator) or to the secondary HSSS.

2.3.3 Stand-by and regeneration of the traps

Traps switch to stand-by position in the cases below :

- the purification efficiency exceeds the specified values for H_2O or CO_2 ;
- H_2O or CO_2 concentrations reach the saturation point in the absorbents ;
- or the operating time of the trap is over 60 days.

When the PreCT is out of operation, a 50 days stand-by period is necessary to have the radioactivity decreased (iodine).

Active noble gases absorbed by CCT are stored for about 50 days and then transferred to the Gaseous Radwaste Treatment System (GRTS).

Traps are regenerated when the purification ratio is < 95 %. The regeneration tests of the COB and the MST are carried out together while the CCT is regenerated apart.

The trap to be regenerated is isolated from the purification loop and connected to the regeneration system.

The regeneration system is a closed loop incorporating :

- a gas circulator,
- a heater,
- the trap to be regenerated,
- a cooler.

COBs, MSTs and CCTs can be used repeatedly after regeneration.

<u>Regeneration of the COB :</u>

Helium is heated, mixed with a content ≤ 0,3 vol % of oxygen and injected into the inlet of the COB. Helium from the COB is cooled to 15 °C and flows back to the circulator.

<u>Regeneration of the MST :</u>

It is necessary to heat up the MST and create a vacuum for desorption of H_2O and CO_2.

The regenerating system is connected to the MST. Hot gas is recirculated until the MST is heated up to about 250 °C. Carbon dioxide and water are extracted and carried with the helium flow. Water vapour extracted from the MST condense in the cooler and is discharged into a collecting tank.

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When the MST reaches 250 °C, heating is stopped and the regenerative gas is released into the GRTS. When the gas pressure in the regeneration loop equalise the pressure in the GRTS, the system is vented down to P < 1300 Pa (10 torr) by vacuum pumping for evacuation of water and carbon dioxide.

The regeneration loop is then filled (injection at the inlet of the heater) with helium from the HSSS up to the atmospheric pressure.

COB and MST are isolated from the regeneration loop and pressurised at the operating pressure of the purification loop. The regeneration is then completed.

The regeneration time for the COB and the MST is approximately 50 h.

Regeneration of the CCT :

The regeneration procedures of the CCT is almost the same as for procedures for the MST except that the CCT is heated to 150 °C instead of 250 °C, and a thawing step must be taken before the low temperature adsorber is heated by the regeneration system.

Active noble gases desorbed by the CCT are stored for about 50 days to have the radioactivity decreased (Kr, Xe) and then transferred to the GRTS.

The regeneration flow rate is 50 kg/h. Helium is heated and injected in the CCT. Regeneration flow is then cooled from 150 °C to 15 °C. When the CCT reaches 150 °C, heating is stopped and the regenerative gas is released into the GRTS.

2.3.4 Helium Sampling and Analysis System

2.3.4.1 Primary helium

In normal conditions, the primary HSAS controls concentration and radioactive levels in the PCS. An automatic sampling method is used in the HTTR. Results are sent to the control room.

The HSAS incorporates an automatic sampling system, an analyser, a compressor, glove boxes, etc. It also includes a carrier gas feed system and a standard gas feed system. The quantities of impurities are analysed by a gas chromatograph coupled with β and γ detectors and dew point moisture monitors.

The primary HSAS extract helium from primary HPS (at the inlet and outlet of the traps) and measure chemical (H_2O, CO_2, H_2, CO, CH_4, N_2, O_2) and radioactive (Kr, Xe, T) impurity concentrations to control the efficiency of the purification system.

The primary HSAS also extract helium from the ACS and the primary PWC. Water content in the gas is measured in order to detect a failure (leak) on He/water exchange tube.

The automatic sampling, and gas chromatography analysis (except H_2O) are carried out in the order below :

- reactor inlet,
- reactor outlet,
- inlet of primary HPS,

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– inlet of CCT,

– outlet of CCT,

– outlet of primary HPS cooler.

Cycle duration : ~ 10 H 30.

The automatic sampling and H_2O content measurements are carried out using 2 dew point moisture monitors (H1 and H2) in the following order :

H1 :

– reactor inlet,

– inlet of primary HPS,

– inlet of CCT,

– outlet of CCT,

– outlet of primary HPS cooler.

H2 :

– reactor outlet,

– outlet of primary HPS,

– outlet of the PWC primary helium circulator,

– outlet of the IHX primary helium circulator.

The gas from the analyser is transferred to the GRTS, the remainder goes back to the PCS through the primary HPS.

2.3.4.2 Secondary helium

The secondary HSS process is similar to that of the primary HSS except that :

– the analysed gas is released to the Ventilation and Air Conditioning System (VACS) of the reactor building instead of the GRTS ;

– in normal conditions, helium is extracted from the secondary PWC for water content control and leak detection on exchange tubes.

The automatic sampling, and gas chromatography analysis (except H_2O) are carried out in the order below :

– reactor outlet,

– inlet of the IHX, on the secondary side,

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– inlet of the secondary HPS cooler,

– inlet of the CCT,

– outlet of the CCT.

Cycle duration : ~ 6 H 20.

The automatic sampling and H_2O content measurements are carried out using H1 and H2 dew point moisture monitors in the following order :

H1 :

– secondary helium circulator,

– outlet of the secondary PWC,

– outlet of the secondary HPS.

H2 :

– outlet of the IHX, on the secondary side,

– outlet of the secondary HPS cooler,

– inlet of the CCT.

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2.3.5 Experimental results of the commissioning test

Commissioning tests of the HPS were performed over the May - July 1999 period [4]. It was the first in service test of the automatic helium sampling system of the HTTR.

Helium was heated by the gas circulators of the circuits and not by the nuclear heat from the core. Helium temperature was 212 °C in the PCS and 210 °C in the SCHS.

2.3.5.1 Rate of impurities elimination

In the course of the tests the variation of the impurities concentration in the primary and secondary helium was estimated.

The rate of impurities elimination in the PCS and the SHCS are given in table 3.

2.3.5.2 Quantity of eliminated impurities

The quantities of impurities eliminated by a trap are calculated using the relation below :

$$R = G(C_{in}-C_{out}) \times 10^{-6} \times M/M_{He} \times t$$

With :

G He gas flow (kg/h)

C_{in} Impurity concentration at the inlet of the trap (vol. ppm)

C_{out} Impurity concentration at the outlet of the trap (vol. ppm)

M Molar mass

M_{He} Molar mass He

T operating time of the trap

From this relation the quantities of impurities eliminated by the purification train in the PCS and the SHCS are given in table 4.

2.3.5.3 Main outcomes

Purification results of the COB and the CCT proved to be satisfactory up to 200 °C .

As regards the PCS, MST efficiency proved to be satisfactory to eliminate CO_2 but not H_2O. As regards the SHCS, MST efficiency proved to be unsatisfactory to eliminate both CO_2 and H_2O. MST efficiency had thus to be improved for next tests.

The automatic sampling system didn't work properly over the test period because of sequencer faults and automated alarm problems. Some parts of the facility had to be corrected.

2.3.6 Complementary missing data

Useful complementary data are missing in the available public data. They deal with :

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- Fresh helium specifications
- More recent results from helium atmosphere in operation (measurements of gas impurities and dust)

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3. High Temperature gas-cooled reactor test module (HTR-10)

3.1 Introduction

The HTR-10 is a 10 MWth pebble-bed gas-cooled test reactor constructed and operated by the Institute of Nuclear Energy Technology (INET) at Tsinghua University in China.

The design of the HTR-10 test reactor is very similar to that of the 200 MW HTR-Module designed by Siemens/Interatom in Germany. He auxiliary system supply the primary circuit with qualified fluid, maintains its quality and permit drainage or refilling.

In the primary system, the helium coolant is circulated by a helium circulator to carry heat from the core to the steam generator. The helium coolant with 3.0 MPa pressure reaches 700 °C at the core outlet and then drops to 250 °C at the steam generator exit.

In the secondary loop, steam from the steam generator drives the steam turbine to generate electricity.

The HTR-10 project is to be carried out in two phases. In the present phase, the reactor with a coolant outlet temperature of 700 °C is coupled with a steam generator providing steam for a steam turbine cycle which works on an electricity and heat co-generation basis.

In a second phase, the reactor coolant outlet is planned to be raised to 900 °C. A gas turbine cycle and a steam reformer will be coupled to the reactor in addition to the steam turbine cycle.

3.2 Primary loop pressure boundary system

The HTR-10 helium primary loop pressure boundary system contains the reactor core, the reactor internals, the steam generator, the hot gas duct, and the primary coolant circulator (see figure 3).

The reactor vessel and the steam generator vessel are arranged vertically and in parallel and are connected by a horizontal hot gas duct vessel. The Helium Purification System (HPS), the helium supply and storage system, the primary loop release system and the thermodynamic measurement system are installed in the HPS cavity, which connects with the steam generator cavity by a rupture disk.

Helium flow reverses at the top of reactor core into the pebble bed, so that a downward flow pattern takes place in it. After being heated in the pebble bed, helium enters into a hot gas chamber in the bottom reflector, and from there it flows with reactor outlet temperature through hot gas duct to the heat exchanging components [9].

The HPS serves the primary circuit, but is not relevant to the safety of the reactor. However, it is important for the reactor operation, since it also serves to mitigate consequences of some malfunctions. Consequently, a post accident purification train is provided.

When a depressurisation of the primary circuit is required the purified hot helium from the He/He heat exchanger is introduced to the post accident cooler, where it is cooled to about 40 °C and

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then released to the helium storage system. A diaphragm compressor[1] with a volume flow rate of 2,2 m^3/h provides the necessary pressure head to drive the helium stream during regulating the pressure of the primary circuit when the primary helium circulator is shutdown.

When an increase of the pressure of the primary circuit is required the helium is introduced into the purification system from the helium storage system.

3.3 Helium purification system

3.3.1 Preamble

The design of the HTR-10 HPS is mainly described in [8]. It is closely derived from the German 200 MW HTR-Module HPS design described in [6].

The HPS of the HTR-10 purifies a bypassed stream from the primary coolant circuit. The purification train is designed for a helium flow rate of 10,5 kg/h, corresponding to a 5% gas change of the helium inventory in primary circuit.

The function of the HPS is to continuously remove from the primary helium coolant, dusts and particles, gaseous impurities such as hydrogen, carbon monoxide, carbon dioxide, water vapour, oxygen, nitrogen, methane including radio-nuclide fission products such as krypton, xenon, etc.

The HPS, shown in the schematic view of figure 4, is mainly composed of a cartridge filter, a Copper Oxide Bed (COB), a Molecular Sieve Absorber (MSA), a Low Temperature Absorber (LTA) and two diaphragm compressors.

The additional post accident purification train consist of a cooler and a moisture separator.

The specifications for anticipated values of gaseous impurity in the primary coolant of the HTR-10 for normal operation are given in table 5.

The specifications for the helium purification system design are given hereafter in term of inlet gaseous impurities for 2000 h continuous duty (vpm) :

H_2O	CO	N_2	H_2	CH_4	CO_2	O_2
1	9	2	9	3	1	1

The purified helium leaving the purification system is returned to the primary circuit with impurities $\leq$ 0.1 vpm for O_2, N_2, H_2O, CO and CO_2, and $\leq$ 0.2 vpm for H_2 and CH_4 respectively.

Samples of the primary coolant helium from the inlet of the HPS and of the process helium from the outlets of the COB, the MSA and the HPS (i.e. the outlet of the LTA), respectively, are analysed to evaluate quantities of impurities by a gas chromatograph, two infrared optical analysers and dew point moisture monitors. The quantities of tritium, krypton and xenon are obtained by employing an ion chamber electrometer.

[1] With another one in stand by

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The purification components are designed for a service life of more than 2000 h at normal operating conditions and are suitable for purification of newly delivered helium. It is anticipated that the purification train must be regenerated after about 2000 h of continuous purification operation.

The HPS also purifies helium transferred from the primary circuit to the storage during depressurisation necessary for maintenance.

The regeneration system includes a cooler, a moisture separator, a diaphragm compressor and a heater. Together with an evacuation system, it is used to regenerate the absorbers and the COB. The regeneration of the COB is processed with an oxygen injection.

3.3.2 Operation of the HPS

During normal operation the primary coolant helium at 250 °C and 3.0 MPa from the outlet of the primary helium circulator is driven to enter the HPS with a flow rate of 10,5 kg/h by the pressure head of the primary helium circulator.

A cartridge filter is set at the entrance of the HPS to separate the dust like impurities. For particles of 5 µm or larger, a retention efficiency of almost 99% can be attained.

In the first "high temperature" stage the helium to be purified flows through the heater where it is heated to 250 °C then into the high temperature COB for oxidation of hydrogen and carbon monoxide. Hydrogen, which includes tritium, and carbon monoxide are converted to water vapour and carbon dioxide, respectively. The oxygen is also simultaneously removed by adsorption of the high temperature copper in the unit.

After passing through the dust filter, the helium at approximately 250 °C enters the He/He heat exchanger, where the helium is cooled by the back helium stream from 250 to 90 °C. The helium temperature is further reduced from 90 to 40 °C in the water-cooler and from 40 °C to approximately 20 °C in the cold helium cooler.

In the second "room temperature" stage a moisture separator separate condensed water from the helium gas. The relative humidity of the primary coolant helium is very low during normal operation, even when cooled to 20 °C. Moisture separation is, therefore, unimportant except in the case of tube ruptures.

After that, the helium flows to the MSA where water vapour and carbon dioxide are removed by adsorption.

In the third "low temperature" stage the helium is cooled to about -140 °C by the heat exchange with returning cold purified helium from the LTA in the low-temperature He/He heat exchanger. The cold helium flows through the LTA, which uses liquid nitrogen to process the helium at approximately -160 °C. Methane, oxygen, nitrogen, noble gases such as krypton and xenon, only traces of which occur as fission products, are retained in the LTA. The purified cold helium, re-warmed up to approximately 10 °C in the low-temperature He/He heat exchanger, and further warmed to 35 °C in the helium cooler, is driven by a diaphragm compressor to the He/He heat exchanger, where it is heated to approximately 185 °C.

After being purified, the hot helium at approximately 185 °C leaves the He/He heat exchanger and is directly sent back to the inlet of the primary helium circulator in the steam generator pressure vessel.

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The function of the post accident moisture separator is to separate condensed water from the helium after a water ingress accident. The water is accumulated in the bottom of the separator, and then trained to the liquid waste system.

The purified hot helium is then introduced into the post accident cooler, where it is cold to approximately 40 °C, and flows to the HSS.

3.3.3 Regeneration of the traps

The regeneration tests of the MSA, LTA and COB are carried out as described below.

MSA

First of all, the helium gas in the entire purification loop is discharged into the purified helium storage via the connected piping and valves until a pressure of 0.6 MPa is reached. The MSA to be regenerated is then isolated from the remainder of the purification loop and connected to the regeneration system.

In the second phase, the regeneration gas is heated to about 280 °C by the heater and is driven to pass through the MSA by the regeneration diaphragm compressor with a flow rate of 10.5 kg/h. The gas is recirculated until the absorber is heated up to about 250 °C (process time ~23 h).

The carbon dioxide and water are extracted and carried to the regeneration system with the helium flow. In the cooler the helium is cooled to about 20 °C. The main fraction of the steam is condensed and separated in the moisture separator. The tritium loaded condensed water is discharged into the radioactive liquid waste system.

In the third phase, the cooler, the moisture separator and the diaphragm compressor of the regeneration system are disconnected, the gas in the MSA is released into the gas waste system and the gas pressure is relieved to a pressure of 0.1 MPa for subsequent evacuation. By vacuum pumping down to P < 100 Pa, the water and carbon dioxide are removed from the MSA with the exception of a very small residual fraction.

In the fourth phase after pressure equalisation for 2 h, the MSA and the regeneration system are pressurised with helium up to 0.6 MPa. With the heater switched off the regeneration system is used to cool the MSA. When a helium outlet temperature of 40 °C is reached at the MSA, the regeneration has been completed and the regeneration system is disconnected from the HPS.

LTA

The regeneration procedures of the LTA are almost the same as for the MSA except that :

- the LTA is heated to 150 °C instead of 250 °C,
- a thawing step must be taken before the LTA is heated by the regeneration system.

COB

The regeneration test of the COB is carry out at 80 °C for about 20 h with 0.52 kg/h of oxygen being continuously injected into the inlet of the COB. Then the system is vented down to P < 100 Pa.

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3.3.4 Complementary missing data

Useful complementary data are missing in the available public data. They deal with :

- Fresh helium specifications
- Information from helium atmosphere in operation (measurements of gas impurities and dust)

4. Conclusion

Some information, issued from public data, on helium specifications, purification system design and helium atmosphere during reactor operation are presented in this report for HTTR, mainly during commissioning tests, and HTR-10 reactors.

But useful complementary data are missing. They deal with :

- Fresh helium specifications
- Recent information from helium atmosphere in operation (measurements of gas impurities and dust)

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Table 1 : HTTR design – Specifications for upper values of gaseous impurities in the primary coolant during normal operation (from [1])

Impurity	Concentration (vpm)
H_2O	0,2
CO_2	0,6
H_2	3,0
CO	3,0
CH_4	0,5
N_2	0,2
O_2	0,02

Table 2 : HTTR commissioning tests - Specified levels of impurity concentration to maintain in the PCS as a function of temperature (from [4])

Impurity (vol ppm)	Temperature at the core outlet (°C)			
	400 £ T < 600	600 £ T < 700	700 £ T < 800	T £ 800
H_2O	200	20	2	0,2
CO_2	600	60	6	0,6
H_2	3000	300	30	3,0
CO	3000	300	30	3,0
CH_4	500	50	5	0,5
N_2	200	20	2	0,2
O_2	20	2	0,2	0,02

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Table 3 : HTTR commissioning tests – Rate of impurities elimination in the PCS and the SCHS (from [4])

Impurity	Concentration range (vol. ppm)	Rate of elimination (vol. ppm/h)	
		Primary helium	Secondary helium
H_2	1 - 0,1	-	$1,4\ 10^{-3}$
	0,1 - 0,01	$9,5\ 10^{-4}$	$9,9\ 10^{-4}$
CO	0,1 - 0,01	$1,9\ 10^{-3}$	$1,1\ 10^{-3}$
CO_2	1 - 0,1	$5,0\ 10^{-2}$	$4,6\ 10^{-3}$
	0,1 - 0,01	$4,2\ 10^{-4}$	$3,7\ 10^{-4}$
CH_4	0,1 - 0,01	$1,4\ 10^{-3}$	$1,6\ 10^{-3}$
N_2	100 - 10	$1,2\ 10^{0}$	-
	10 - 1,0	$1,3\ 10^{-1}$	$5,2\ 10^{-1}$
	1,0 - 0,1	$2,6\ 10^{-2}$	$6,7\ 10^{-2}$
	0,1 - 0, 01	$1,2\ 10^{-3}$	$3,9\ 10^{-3}$
O_2	10 - 1,0	$2,8\ 10^{-1}$	$5,8\ 10^{-1}$
	1,0 - 0,1	$1,4\ 10^{-2}$	$6,4\ 10^{-2}$
	0,1 - 0, 01	$1,1\ 10^{-3}$	$4,2\ 10^{-3}$

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Table 4 : HTTR commissioning tests - Quantity of impurity eliminated by the purification train in the PCS and the SCHS (from [4])

Impurity	Molar mass M	Primary circuit			Secondary circuit		
		Gas flow G (kg/h)	Ó C_{in}-C_{out} (vol. ppm)	Quantity of impurity eliminated R (kg)	Gas flow G (kg/h)	Ó C_{in}-C_{out} (vol ppm)	Quantity of impurity eliminated R (kg)
H_2	2	200	0,04	$1,2\ 10^{-5}$	10	16,0	$3,610^{-4}$
CO	28		0,00	0,0		4,26	$1,1\ 10^{-3}$
H_2O	18		1334,07	$7,5\ 10^{-1}$		4487,68	1,1
CO_2	44		7,72	$5,1\ 10^{-2}$		41,71	$2,2\ 10^{-2}$
CH_4	16	50	0,01	$5,9\ 10^{-6}$		4,22	$5,7\ 10^{-4}$
N_2	28		146,85	$1,7\ 10^{-1}$		354,95	$7,9\ 10^{-2}$
O_2	32		21,88	$2,8\ 10^{-2}$		102,56	$2,0\ 10^{-2}$

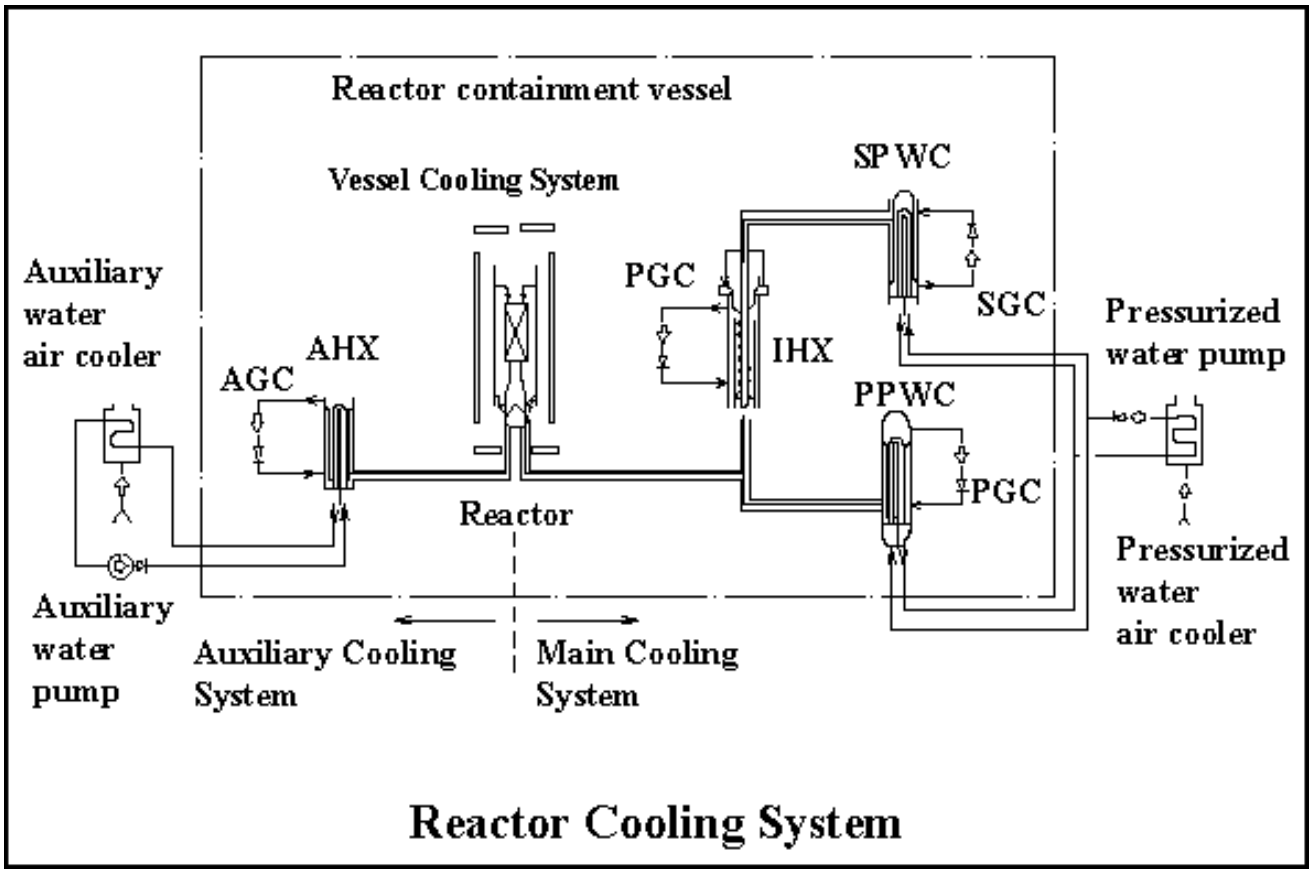
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Table 5 : HTR-10 design – Specifications for anticipated upper values of gaseous impurity in the primary coolant during normal operation (from [8])

Impurity	Concentration (vpm)
H_2O	0,2
CO_2	-
H_2	3,0
CO	3,0
CH_4	1
N_2	1
O_2	-

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Figure 1 : Flow diagram of the HTTR cooling system (from [5])



IHX : Intermediate Heat Exchanger

PPWC : Primary Pressurised water cooler

PGC : Primary Gas Circulator

SPWC : Secondary Pressurised Water Cooler

SGC : Secondary Gas Circulator

AHX : Auxiliary Heat Exchanger

AGC : Auxiliary Gas Circulator

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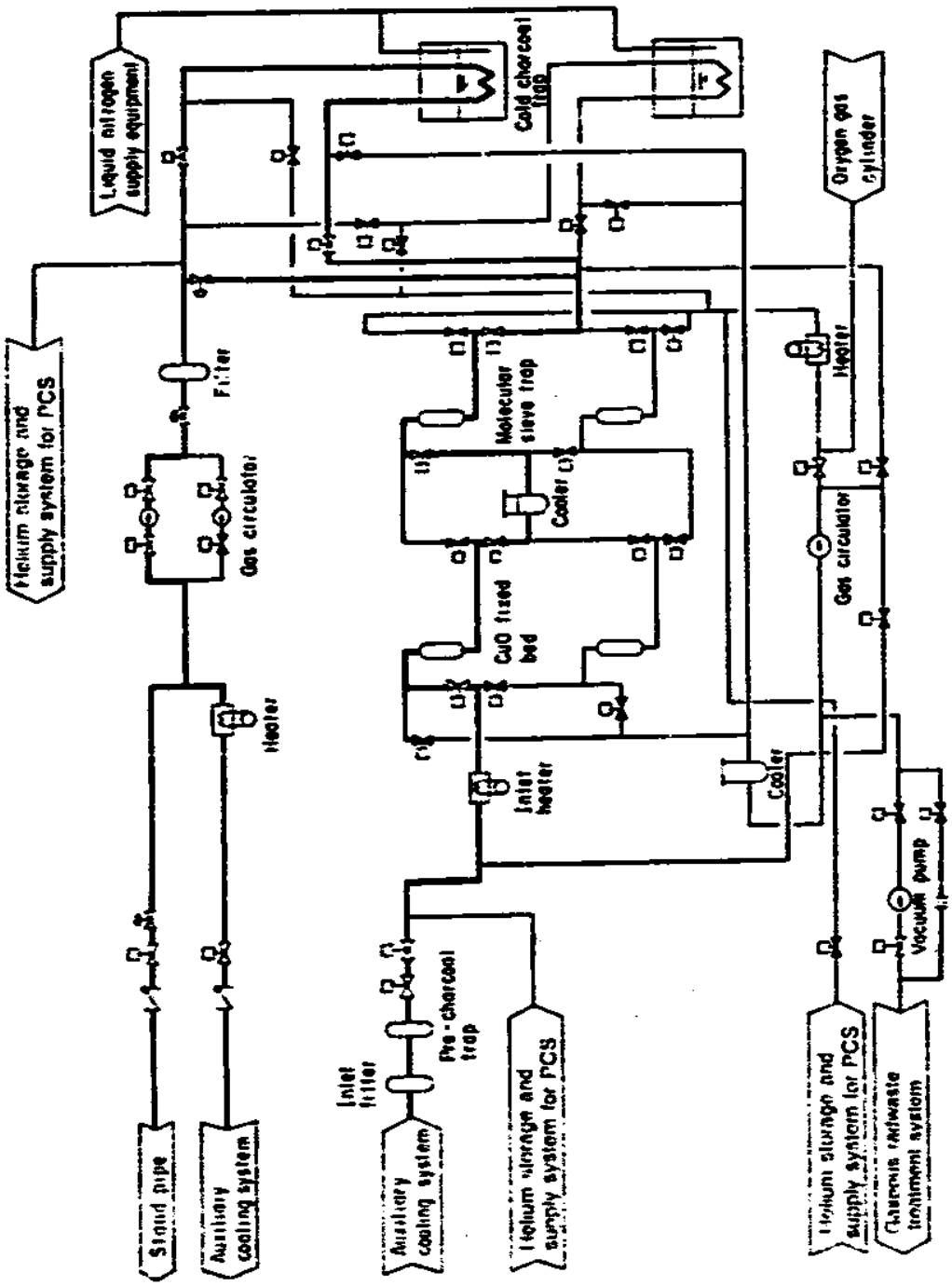
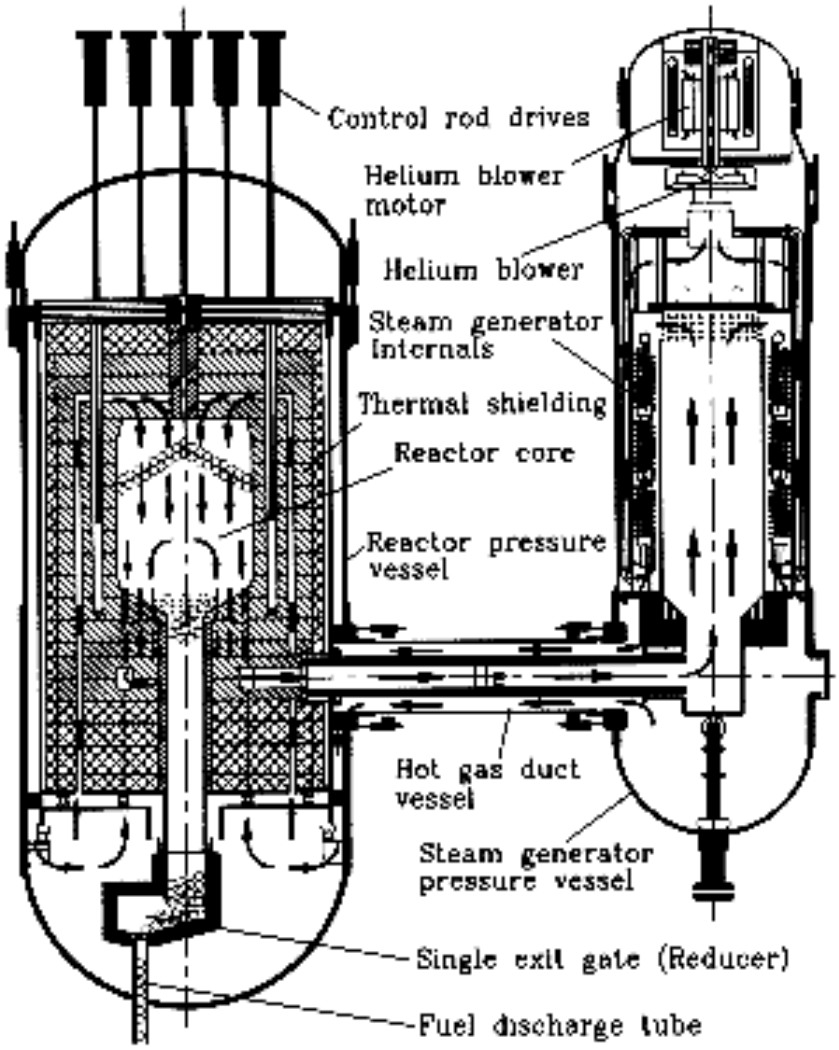


Figure 2 : HTTR design - Main flow diagram of HPS for PCS (from [2])

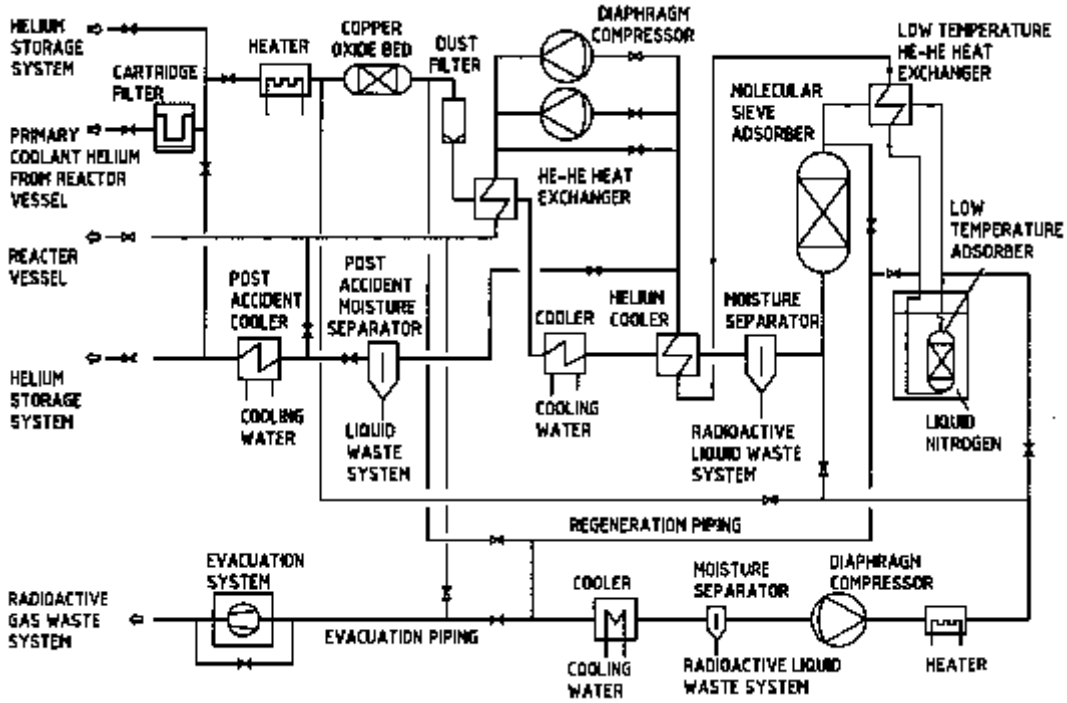
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Figure 3 : HTR-10 design - Main components of the primary loop pressure boundary (from [11])



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Figure 4 : HTR-10 design - Schematic of the HPS (from [8])



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