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Safety aspects of the design of a PWR Gaseous Radwaste treatment system using Hydrogen Recombiners

R. Glibert - G. Nuyt - S. Hérin - P. Fossion

ABSTRACT

PWR Gaseous Radwaste treatment system is essential for the reduction of impact on environment of the nuclear power plants.
Decay tank system has been used for the retention of the radioactive gaseous fission products generated in the primary coolant.
The use of a system combining decay tanks and hydrogen recombiner units is described in this paper.
Accent is put on the safety aspects of this Gaseous Radwaste treatment facility studied by BN for a Belgian Power Plant.

1. INTRODUCTION

The Gaseous Radwaste treatment system regulates the discharge of activity waste gases to the atmosphere. These waste gases are generated from the primary coolant and are primarily hydrogen containing minor amounts of fission gases such as xenon, krypton and iodine.

Hydrogen recombiner provides a significant off-gas volume reduction and also decreases the hydrogen explosion hazard. The safety aspects of its use in a pressurized water reactor gaseous radwaste treatment system using decay tanks are analysed in this paper.

2. GASEOUS EFFLUENTS FROM PRESSURIZED WATER REACTOR

Gaseous effluents to be handled by the radwaste gas treatment system is depending on the operation of the P.W.R.

2.1. Normal operation

During the normal operation the quantity of gaseous effluents to be handled is small : it corresponds to the gases stripped from the shim bleed (chemical and volume control loop) and to the cover gas of equipment provided for the treatment of the primary coolant.

2.2. Shut down period

The reactor coolant usually contains about 35 cm^3 of hydrogen per kg of water to inhibit radiolytic decomposition of the coolant. During the shut down period, the reactor coolant releases the dissolved hydrogen and traces of radioactive material when the primary coolant is cooled and depressurized. The hydrogen rich phase originates mainly from the chemical and volume control tank. A final sweeping of this tank is performed with fresh hydrogen followed by nitrogen.

2.3. Starting period

During the starting of the power plant it is necessary to obtain a level of 35 cm^3 of hydrogen per kg of water in the primary coolant. For this, fresh hydrogen is introduced into the chemical and volume control tank. The gas leaving this tank is a mixture of hydrogen and nitrogen (previously introduced) and will be handled again by the Gaseous Radwaste treatment System.

3. PRESSURIZED WATER REACTOR RADWASTE GAS TREATMENT SYSTEM DESCRIPTION

The P.W.R. Radwaste gas treatment system described hereafter relates to a system foreseen for a Belgian nuclear power plant (see Fig. 1).
This system uses pressurized storage tanks for the radioactive decay of gaseous fission products (xenon, krypton and iodine), catalytic recombiners to remove the excess of hydrogen and allows the recycling via storage tanks of the cover gas of equipment devoted to the treatment of the primary coolant.

The gaseous effluents are collected in three separate headers :

- header collecting vents from equipment included in the chemical and volume control loop of the primary circuit : primary coolant off-gas
- header directly connected to the volume control tank : volume control tank off-gas
- header collecting the cover gas of equipment devoted to the treatment of the primary coolant : cover gas.

Primary coolant off-gas is compressed into storage tanks and held for radioactive decay prior to release to the atmosphere.

Volume control tank off-gas (off-gas with a high percentage of hydrogen) is collected in a pressurized storage tank containing nitrogen free of hydrogen and is recirculated through a catalytic recombiner unit which removes the hydrogen. Then, it is held for radioactive decay before release.

The cover gas from the primary coolant treatment system is sent to the decay tanks. If required (exceptional) excess of hydrogen can be removed by sending gaseous effluent to a recombiner unit. In general, the activity level of the cover gas is low and can be recycled back to the primary coolant treatment system.

4. CATALYTIC RECOMBINER AND SAFETY

Catalytic recombiner controls the level of hydrogen in all the PWR Gaseous Radwaste treatment system. Consequently it reduces the explosion hazard and it is thus, an important safety factor.

Indeed a lot of incidents happening to light water power reactor (mainly for BWR) was due to hydrogen explosion [1].

However catalytic recombiner brings itself some hazard (risk of explosion) if it is operated with gas mixture in explosion conditions.

4.1. Gas mixture explosion conditions

Gas mixture conditions each required but not sufficient to get explosion are the following [2] [3]

- presence of oxydable gas in sufficient quantity
- presence of sufficient quantity of oxygen in close mixing with the oxydable gas
- presence of an ignition source.

- Hydrogen content

The low and high limits of flammability of hydrogen-air mixtures at atmospheric pressure are respectively 4 and 75 volume percent hydrogen : under the same conditions the detonation limits are respectively 18 and 59 volume percent hydrogen.

- Oxygen content

  From above a 5.2 volume percent of oxygen in a nitrogen-hydrogen-oxygen gas mixture is necessary to meet the flammability conditions and 8.5 volume percent of oxygen in the same gas mixture to meet the detonation conditions.

- Ignition source

  For a hydrogen-air mixture having a 25 volume percent of hydrogen and 75 volume percent of air the spontaneous ignition temperature is 524°C. In this case if the initial pressure is 7.8 bars (abs) the overpressure due to the detonation is 5 bars.

4.2. Recommended gas operating conditions

It results that the following rules are recommended and generally used to avoid any risk of inflammation or detonation for a hydrogen-oxygen-nitrogen mixture

- The maximum volume percent of hydrogen in the gas mixture will be 4
- The process temperature will remain below 524°C
- The maximum volume percent of oxygen in the gas mixture will be 2

5. SAFETY EVALUATION OF THE RECOMBINER SYSTEM

The process flow diagram (Fig. 2) shows the various components, process flow paths, instrumentation and controls of the recombiner system.

5.1. System description

The gaseous effluents (nitrogen + hydrogen) enter one of the two recombiner units at a constant flow rate and pressure (60 Nm^3/h, 2 bars). A pressure controller located on the common header of the two recombiner units maintains a constant pressure.

Oxygen is fed through a valve controlled by the outlet hydrogen analyser (maximum H_2 content at the outlet 0.1 %). The gas mixture having a maximum concentration of respectively 4 and 2 volume percent of hydrogen and oxygen and saturated with water is filtrated and warmed before entering into the catalyst vessel in order to avoid condensation on the catalyst and thus to reduce its efficiency.

The catalyst bed promotes the reaction of hydrogen and oxygen, forming water vapour. This reaction is exothermic : a hydrogen content of 4 % gives a temperature increase of about 290°C.

Gas leaving the recombiner unit is cooled by flowing through a heat exchanger. The wet gas is separated into saturated gas and liquid water in a demister. Liquid water is discharged as liquid waste. The outgoing gaseous effluent is continuously analysed, sucked by a compressor and discharged into a decay tank.

Besides the previous equipment required to assure the recombination function, additional equipment is provided either to avoid any gas mixture explosion situation to occur or to reduce the consequences of a potential accident (inflammation or explosion).
For each recombiner unit this specific equipment is the following :
- at the inlet of the recombiner an analyser measures the H_2 content in the gaseous effluent
- on the oxygen feed line a flow rate limiting device prevents an excessive oxygen introduction
- a shock trap is included in the prefilter
- after the oxygen addition an analyser measures the O_2 content in the gaseous effluent
- a flame trap is located just before the catalyst vessel
- a temperature detector located inside the catalyst vessel measures the temperature of the exothermic recombination reaction.

- A pressure relief valve and a pressure detector are located after the recombiner and will operate or order action on the circuit in case of explosion or abnormal overpressure
- After the heat exchanger a temperature detector prevents any abnormal temperature
- After the demister an analyser measures the O_2 content in the outgoing gasecus effluent.

5.2. Safety evaluation

Considering the recommended gas operating conditions as safety criteria,the level of safety of this recombiner system can be evaluated.

To do so, the general design and the quantity of safety devices of the recombiner system are considered.

5.2.1. Design of the recombiner system

- The circuit is such that hydrogenated gas stream flows always through a decay tank before its treatment in a recombiner unit.
  So a dilution of a potential high percent of H_2 is automatically obtained.
- A stand-by recombiner unit is installed to ensure the recombination function in case of failure of the first unit.
- Codes and standards used for the design and manufacture including levels of quality assurance for all the components of the recombiner system comply with high quality requirements. So the various components of the system are designed to meet structural integrity requirements under steady state loading seismic conditions and plane crash.
- All the electrical components of the system are explosion proof
- A by-pass of the recombiner system is foreseen in case of any incident or abnormal situation.

5.2.2. Safety devices

As a general rule the quantity of safety devices has been choosen in such a way that the failure of one single device does not lead to hazardous situations and that, independently of the other precautions taken (general design, conservative operating conditions). Two cases are considered to illustrate this rule

- quantity of safety devices to prevent a hydrogen explosion
- quantity of safety devices to reduce the consequence of a hypothetical explosion.

5.2.2.1. Preventing a hydrogen explosion

Recommended operating conditions are used as safety criteria for H_2 and O_2 content in the gaseous effluents.

If the H_2 percentage volume rises to 4 or more

- inlet H_2 analyser gives a signal which cuts off the O_2 feed and diverts the unsafe gaseous flow through the by-pass
- the temperature detector located in the recombiner vessel measures the increase of temperature due to the exothermic reaction, cuts off the O_2 feed and diverts also the unsafe gaseous flow through the by-pass

If the O_2 percentage volume rises to 2 or more

- inlet and outlet O_2 analysers give signals which cut off O_2 feed
- in addition a potential introduction of excess of O_2 is avoided by the limiting flow rate device located on the O_2 feed line

5.2.2.2. Minimizing the consequence of hydrogen explosion

In the case of a hypothetical explosion the following safety devices are used to minimize the consequences :

- a pressure relief valve discharges the gaseous effluents into a decay tank
- a pressure sensor gives a signal which isolates the recombiner circuit and diverts the inlet gaseous flow through the by-pass
- a shock trap located inside the prefilter dissipates the energy of the blast wave and decreases thus the risk of failure of the up-stream equipment including the connected decay tank
- a flame trap located before the recombiner vessel protects the circuit up-stream the recombiner including the connected decay tank by avoiding flame propagation up-stream this vessel.

CONCLUSIONS

- By controlling the level of hydrogen in the gaseous radwaste treatment system, hydrogen recombiner improves the safety of such installation

- Potential hazardous event resulting from its use can be easily minimized by a suitable design of the system

- In addition the use of a recombiner system allows to reduce the volume of gaseous effluent to be stored improving thus the hold up period for a given storage tanks system.

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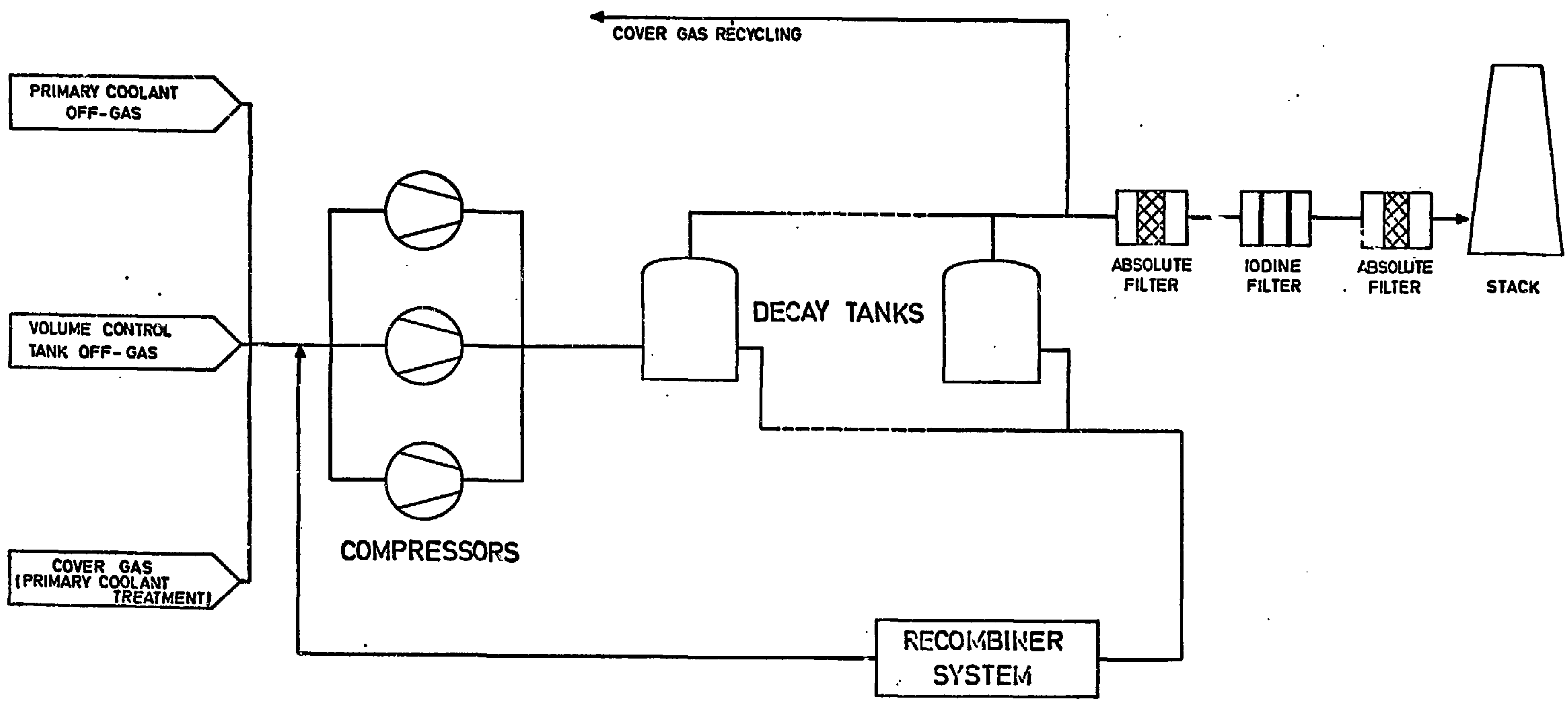
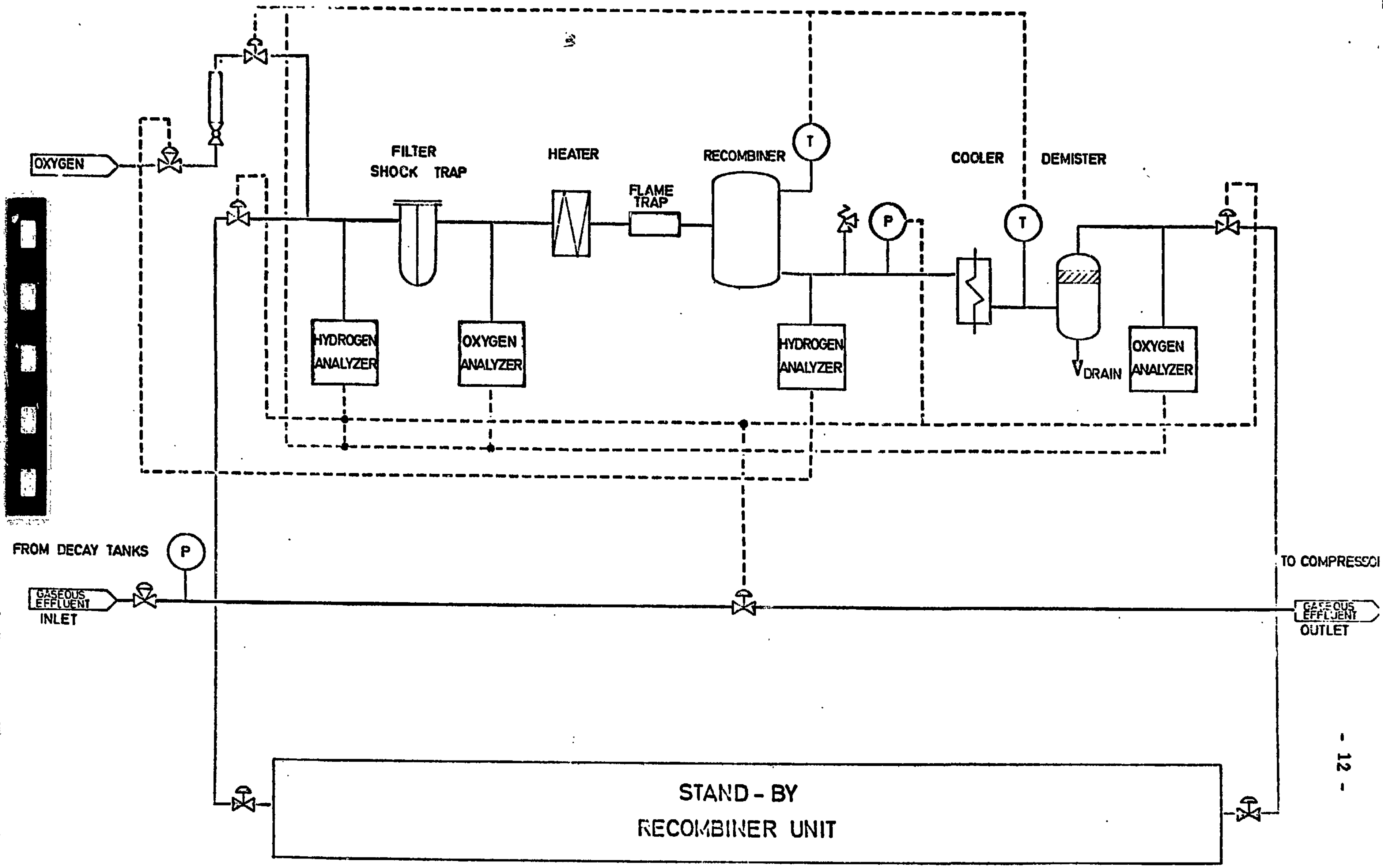


PWR RADWASTE GAS TREATMENT SCHEME.

Fig. 1



RECOMBINER SYSTEM PROCESS FLOW DIAGRAM.

Fig. 2