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Water helium mixture for use in neutron sources as premoderator, coolant and for leak detection at the same time

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Abstract. Subject of the present report is the investigation of the feasibility of using helium as tracer gas for leak detection for a water system in close vicinity to a cryogenic surface.

In order to minimize the heat load to the hydrogen moderator, a vacuum isolation is necessary. This is achieved by adding a second vessel that surrounds the cold moderator. Due to excessive nuclear heating the second container wall has to be actively cooled. This cooling can be realized by the water used as a premoderator. A leak in any of the vessels must be possible to detect by the machine protection system and the target safety system, in order to take appropriate action to prevent further unacceptable consequences. The following scenarios are possible: In case of a big crack in one of the two vessels the vacuum would collapse and thus the situation would be detected. For capillary cracks in the moderator vessel small amounts of hydrogen will flow into the vacuum gap and vaporize. These hydrogen molecules can be detected at the vacuum pump. However, for capillary cracks in the vacuum wall small amounts of water would flow into the vacuum gap. The water would vaporize first and then freeze out as soon as it gets in contact with the cold surface of the liquid hydrogen moderator vessel. Thus, a layer of ice can build up until it forms a thermal bridge. In this case, the vacuum would not collapse and no detectable gas will reach the vacuum pump. Such a crack can therefore remain undetected. In order to handle the last mentioned case the basic idea is to mix the water of the premoderators with small amounts of helium. Thus, the helium and water mixture may be used simultaneously as a premoderator, as a coolant and as a leak detection mechanism. The ongoing studies will show whether it is feasible to inject helium into the water system, that helium will not freeze out together with the water and that it will find its way to the detection system at the vacuum pump.

1. Introduction

In the present report, some incident scenarios for the cold LH2 moderator system are considered and measures to remedy the situation are discussed. This consideration has focused on the pressure vessel of the cold source and possible leakage of the used fluids due to assumed cracks in the structure material. Such incidents can only be controlled sufficiently, if they are detected as soon as possible. Fig 1 shows a simplified horizontal section through the cold Moderator vessel including vacuum insulation and thermal Moderator.

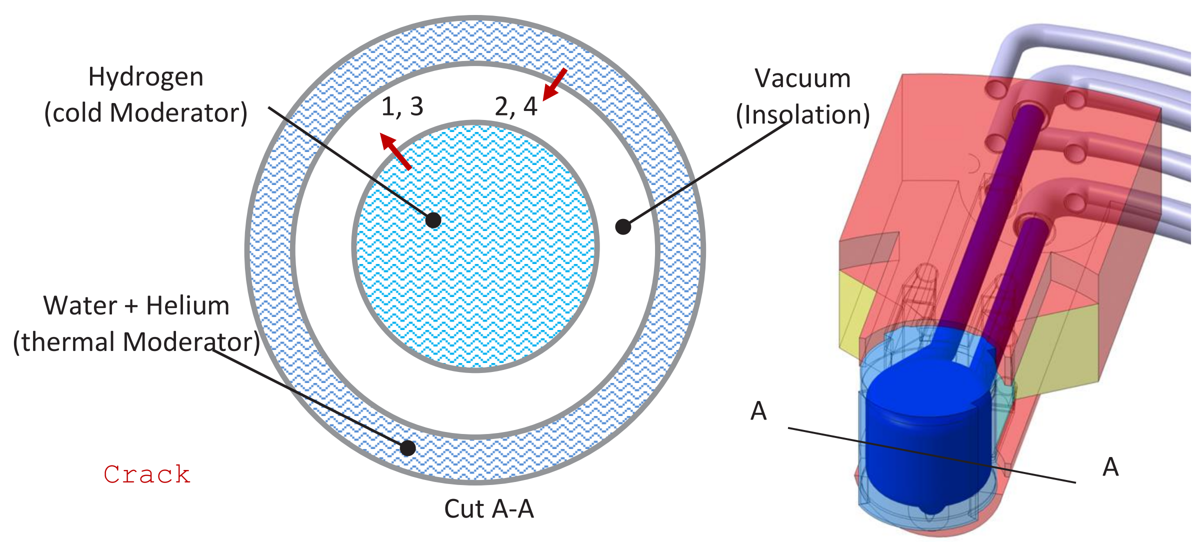

Figure 1. Simplified sectional view of the cold and thermal Moderator

We assume that the insulation vacuum is permanently pumped. At the vacuum pump measuring devices are installed which allows the detection of H_2 and He. A distinction is made between the following four incidents:

1 **Large cracks in the inner vessel wall (cold Moderator):**
A large amount of hydrogen flows into the vacuum gap. The vacuum collapses. This can be detected at the vacuum pump. Measures can be taken.

2 **Large cracks in the vacuum wall (inner wall of the thermal Moderator):**
A large amount of water flows into the vacuum gap. The vacuum collapses. This can be detected at the vacuum pump. Measures can be taken.

3 **Hairline cracks in the vessel wall (cold Moderator):**
Small amounts of hydrogen flows into the vacuum gap and evaporate. The hydrogen molecules can be detected at the vacuum pump. Measures can be taken.

4 **Hairline cracks in the vacuum wall (inner wall of the thermal Moderator):**
Small amounts of water flows into the vacuum gap. The water evaporates and freezes at contact with the cold surface of the Moderator. It forms a layer of ice, potentially building a thermal bridge. The vacuum does not collapses and no detectible gas can be found at the vacuum pump. Accordingly, measures cannot be taken.

Since incident four cannot be controlled without additional measures, in the following, a solution for this purpose is investigated. The basic idea is: Adding a gas to the water of the thermal Moderator up to the solubility limit and use it as a leak detection gas. The gas should not condense or freeze out while in contact with the cold moderator surface (20 K), so that it can be detected at the vacuum pump. The only gas fulfilling this requirement this is helium, because it is the only substance that remains a gas at the present conditions. The disadvantage is that helium has the lowest solubility of all gases (at 20°C and 1 bar are 1.5 mg helium in 1 kg water soluble). Therefore, first it should be demonstrated that the helium can be reliably and homogeneously dissolved in the water. In a second step, it has to be shown that the helium actually reaches the measuring device or if it is probably trapped by the water that freezes on the cold surface.

2. Measurement setup

Figures 2 and 3 are showing the test setup:

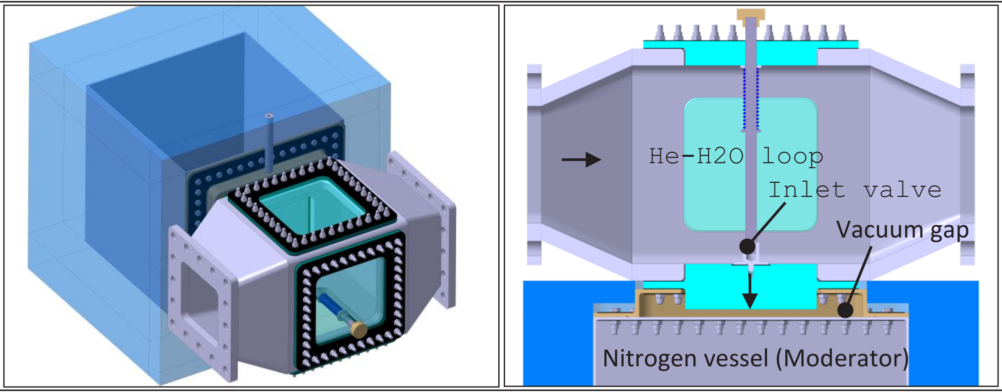

Figure 2. He leak detection test setup, left isometric CAD view, right CAD sectional view

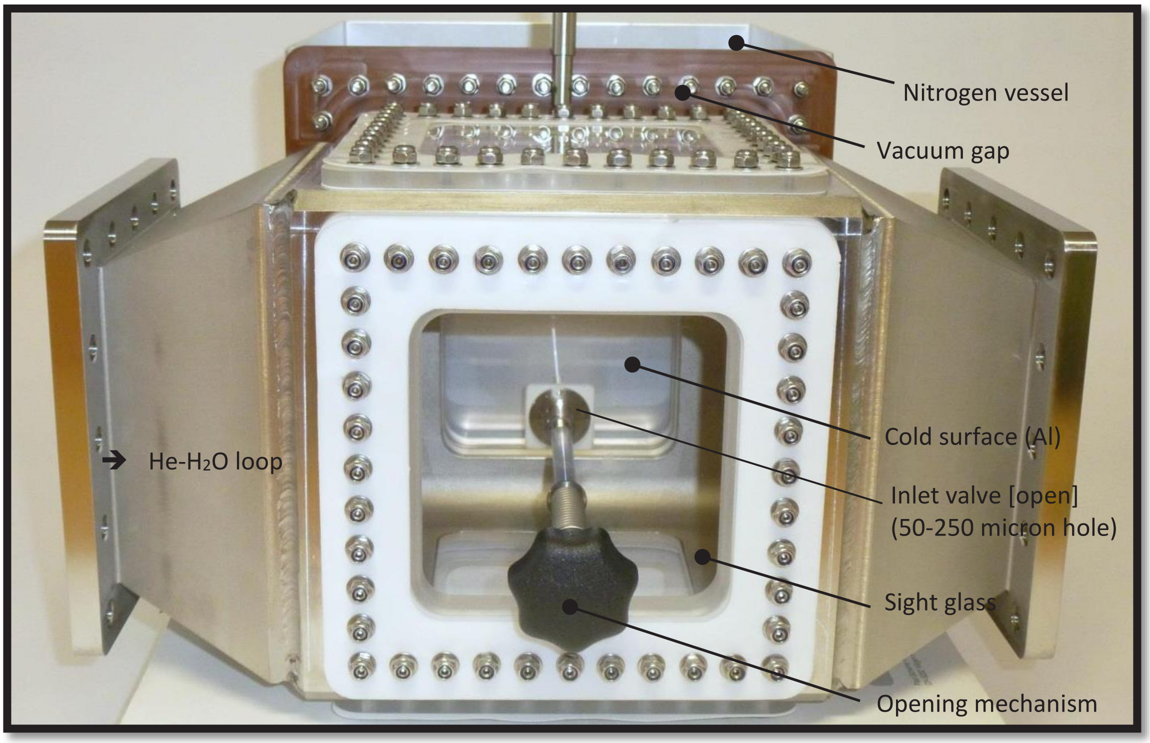

Figure 3. He-leak detection test setup during pre-assembly of the module

To simplify the test setup a liquid nitrogen filled, insulated Aluminium vessel is used as a substitute for the Moderator. The H_2O-He loop and the liquid nitrogen vessel are connected leaving a space to be pumped down simulating the 5 mm vacuum gap. The resulting space is constantly evacuated and monitored for helium gas. The rectangular channel with flowing H_2O -He mixture is equipped with an adjustable valve, which can be operated from outside the channel by a rotary knob. Cracks of various sizes (50 microns to 250 microns) are simulate by micro drilled holes in the glass wall between H2O-He and vacuum. When the valve is open, a portion of the H_2O -He mixture enters the vacuum space. To observe the behaviour of the water vapour and ice formation, the thermal Moderator loop is equipped with quartz glass windows on all four sides. The window between the vacuum chamber and the fluid loop includes a recess for the interchangeable "cracks" that were laser cut into small quartz glass plates (see fig. 4).

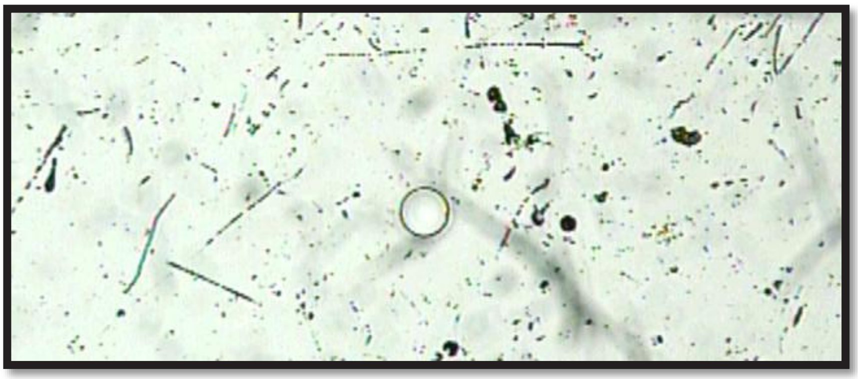

Figure 4. Microscope picture of one of the "cracks" (50…250 μ m)

A mobile He injector provided by the company DELU AG is used to inject the helium. Originally, this system was developed for leak detection of underground supply lines. Helium can then be detected above ground helping to determine the location of the leak and thus reduce the amount of necessary excavations. With this system, the helium can be permanently injected and measured up to the solubility in water.

The mixture was circulated in a closed loop under a slight overpressure. The helium was injected in a bypass. Figure 5 shows the assembled test setup.

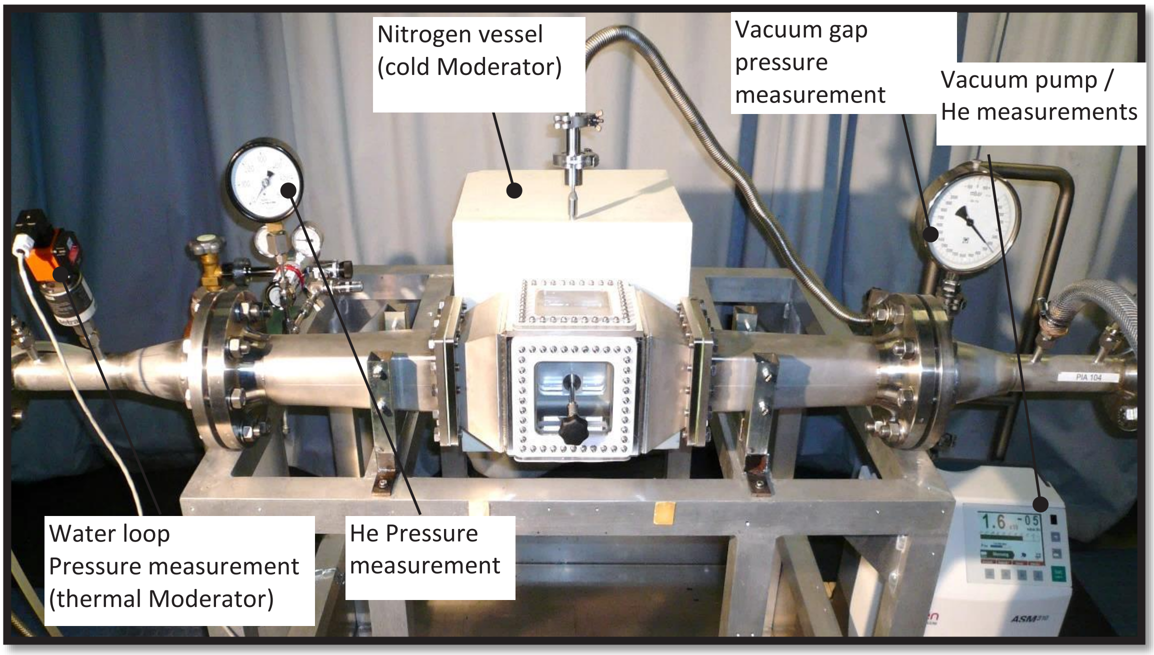

Figure 5. He- leak detection test setup with helium injector (provided by DELU AG)

3. Experimental results

The first test was performed without cold surface, i.e. the nitrogen vessel was not filled. Helium was injected up to the solubility limit in the water. After the valve is opened briefly, the mixture entered into a vacuum gap. The water is evaporated (see fig. 6) and helium could be reproducibly detected at the vacuum pump. This experiment was performed three times.

Figure 6. Incoming water helium solution evaporates due to the vacuum. Helium frees itself from the solution and can be measured

In the second test, the nitrogen vessel was filled with liquid nitrogen and cooled down to about 77 K. Helium was injected up to the solubility limit in the water. Then, the valve was opened again shortly for a few seconds. The mixture entered the vacuum chamber, the water froze immediately on the cold surface and the helium was again detected reproducibly at the vacuum pump (see fig. 7). This experiment was also repeated three times.

Figure 7. On the cold surface of the "moderator" frozen water. Helium diffuses through the ice and can be measured

In the third and last set of experiments, the nitrogen vessel was filled and cooled down. This time plain water was used instead of a H_2O-He mixture. The valve remained permanently open during this experiment. Water entered into the vacuum gap forming a large ice layer on the cold surface. After some time the ice bridged the entire 5 mm vacuum gap and consequently the leak was blocked (sealed) by the formed ice. Surprisingly this did not lead to a destruction of the glass wall from the vacuum side towards the water. After the leak was self-sealed by the freezing water, helium was injected into the water loop. Soon after this, helium was detected at the vacuum pump. This experiment showed impressively that, first, forming ice do lead to building a thermal bridge but did not lead to immediate destruction of the structure. Second, the helium was able to diffuse through the watertight ice block still allowing detection of the crack.

For conclusion figure 8 shows the so-called "soda pop" effect. As soon as the system pressure is reduced, the solubility of the helium is also decreased. Thereby helium gas bubbles are forming in the water. This is a sign for the water to be well saturated with helium. As soon as the system pressure increases again, the injector automatically feeds helium back into the water up to the solubility limit.

Figure 8. Helium fog (detection gas) results from pressure reduction

4. Summary & Outlook

The report showed that a leak detection system with the used components is possible in principle for using in the ESS facility. For secure and automated operation, it is however, necessary to make some modifications of the Helium injector used. For that, the manufacturer of the injector (DELU AG) is ready to cooperate. The following modifications are necessary for ESS:

- automation of the system, currently an operator directly at the system is necessary
- scaling of the injector, depending on the water pressure and loop volume
- definition of the circuit implementation, in the main loop or in a bypass (bypass takes longer but has lower pressure loss)