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Liquid hydrogen cold moderator optimisation at the Budapest Research Reactor

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Abstract

At the Budapest Research Reactor (BRR) the main functional element of the planned cold neutron source (CNS) is a special moderator cell filled with liquid hydrogen and placed at the end of a horizontal beam channel in the Be reflector close to the maximum of thermal neutron distribution. The moderator cell is inside an explosion proof vacuum case preventing the reactor itself from any damage even in the worst possible accident. Two versions of the moderator cell both directly cooled with cold He gas are compared.

Keywords: Cold neutrons; Neutron sources; Neutron instruments

The *cryogenic system* of CNS shall dissipate the energy release in the liquid hydrogen as well as in the construction materials of the moderator cell due to heavy nuclear radiation. The LH_2 is heated mostly by the slowing down neutrons while the Al walls of the cell almost entirely by the gamma radiation. The calculated specific energy releases at 10 MW reactor power in H_2 and in Al are $q_H = 1.1$ W/g and $q_{Al} = 0.13$ W/g, respectively. In case of our small moderator cell (0.4 l, about 30 g of LH_2 and 360 g of Al) the low estimated heat release (about 100 W) makes feasible the implementation of a heat exchanger built together with the LH_2 moderator i.e. the direct cooling of the condensed hydrogen in a double walled moderator cell by through-flow of cold He gas [1, 2]. The pressure and temperature of He gas with 10 g/s mass flow supplied from the cold box to the LH_2 moderator are 0.15 Mpa and 14 K, respectively. At the start of CNS operation hydrogen gas is cooled down and condensed in the moderator cell rinsed by cold He gas. At stationary operation the moderator cell is completely filled with liquid H_2 subcooled to 17–19 K temperature and radiation heat release in is dissipated by the cold helium. Mechanical impurities, activated small solid particles are removed from He gas by a fine filter in the return transfer line. The cryogenic parameters of the CNS systems are summarised in Table 1.

Hydrogen system. The LH_2 moderator cell is connected to the buffer volume placed outside of the reactor hall trough a single hydrogen transfer line which is normally open both in warmed up and cooled down state. When warmed up, almost the whole hydrogen inventory is in the buffer volume under 0.22–0.25 MPa pressure at ambient temperature. When operating and the moderator cell is filled with condensed LH_2, the pressure drops to 0.12–0.15 MPa level and most of the hydrogen amount is inside the moderator cell. After operation (normally about 10 days) the warmed up hydrogen evaporates and is evacuated to the buffer volume. A fine filter in the hydrogen transfer

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Table 1

Parameter	Value
Working medium	Hydrogen
Volume fraction of impurities in LH_2, less than	
Oxygen (%)	1.0×10^{-3}
Nitrogen (%)	2.0×10^{-2}
Volume of the LH_2 moderator cell, *l*	0.4
Total radiation heat load (W)	81
Heat load in LH_2 (W)	34
Heat load in the walls of the LH_2 moderator cell (W)	47
Hydrogen buffer volume (m^3)	0.5
Pressure in the vacuum case (Torr)	1.0×10^{-5}
Pressure in the hydrogen loop, warmed up (MPa)	0.215
Pressure in the hydrogen loop, cooled down (MPa)	0.150
Helium parameters at cooled down LH_2 moderator	
Mass flow (g/s)	10.0
Pressure (MPa)	0.15
Inlet temperature (K)	14.0
Outlet temperature (K)	15.8
Resistance of the loop (kPa)	14.0
Helium parameters at warmed up LH_2 moderator	
Mass flow (g/s)	1.0
Pressure (MPa)	0.3
Inlet temperature (K)	293
Outlet temperature (K)	295
Resistance of the loop (kPa)	54.0
Mass flow in the cooling loop of the He blanket (g/s)	5.0

(5 μm pore size) keeps back the radioactive impurities.

For safety reasons, not only the in pile part but the whole hydrogen inventory i.e. the buffer volume, the transfer line and the interlocked valve block are included in controlled inert gas containment. The radiation heat load on the in pile vacuum case containing the LH_2 moderator is removed by the surrounding safety He blanket circulating with 5 g/s mass flow supplied from the helium purifier unit at about 300 K temperature.

The proposed design with direct cooling of the condensed hydrogen in double walled moderator cell is improving the safety characteristics due to minimisation of the necessary hydrogen amount and making far less complex the out-of-pile hydrogen system. Also the extra inert gas barrier around the LH_2 moderator cell preventing from the hydrogen-air mixture formation is an additional safety enhancing factor.

Moderator cell. To minimise the heat load of the LH_2 moderator with optimised cold neutron output simultaneously, two design versions were analysed, a disk shaped moderator cell and a cylindrical one. The diameter and mean thickness of both cell versions are 12 cm and 4 cm, respectively.

Disk shaped moderator cell. The temperature of the liquid hydrogen in the centre of the moderator cell is $T_{H_2} = T_{He} + \Delta T$, where T_{He} is the He temperature and ΔT is the total temperature difference on the wall of cell and on the liquid hydrogen layer. According to calculations, $\Delta T = 7.6$ K and the He temperature is $T_{He} = 14.5$ K so $T_{H_2} = 22.1$ K. At $p = 0.15$ MPa pressure the saturation temperature of hydrogen is $T_S = 21.8$ K, therefore the hydrogen is not completely condensed. Increasing the hydrogen amount in the system and the working pressure to $p = 0.25$ MPa, the saturation temperature increases to $T_S = 23.85$ K and in this case a $\Delta T_S = 1.75$ K subcooling can be achieved.

Cylindrical moderator cell. Both the inner and outer surfaces of the inside wall between the H_2 and He of the cylindrical box shaped moderator cell are grooved to enhance the mechanical strength of the construction and to increase the heat exchanger surface. The optimal direction of He trough flow is also forced by the grooves. In this case the calculated total temperature drop $\Delta T = 5.9$ K, the temperature of liquid hydrogen in the centre of the moderator cell is $T_{H_2} = 20.3$ K, therefore at $p = 0.15$ MPa pressure $\Delta T_S = 1.5$ K subcooling can be achieved.

Comparing both versions the cylindrical cell seems to be superior without need for increasing the pressure in order to increase the boiling point of the hydrogen.

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