CH01000256

NEW RESEARCH POSSIBILITIES AT THE BUDAPEST RESEARCH REACTOR

(Installation of a Cold Neutron Source)

Tibor Hargitai and István Vidovszky
KFKI Atomic Energy Research Institute
H-1525 Budapest POB 49, Hungary
Fax: + 36 1 395 92 93

ABSTRACT

The Budapest Research Reactor is the first nuclear facility of Hungary. It was commissioned in 1959, reconstructed and upgraded in 1967 and 1986-92. The main purpose of the reactor is to serve neutron research. The reactor was extended by a liquid hydrogen type cold neutron source in 2000. The research possibilities are much improved by the CNS both in neutron scattering and neutron activation.

1. Introduction

The tank-type Budapest Research Reactor was first commissioned in 1959 as a 2 MW thermal power reactor, using EK-10 (10% enriched) fuel. The first reconstruction and upgrading project took place in 1967, when new fuel type was introduced (VVR-SM, 36% enrichment) and the power was increased to 5MW. The reactor was operated till 1986, when based on a governmental decision the reactor was shut down for a major reconstruction and upgrading project. The reconstruction was finished in 1990, but due to the political changes in the country the reactor was re-commissioned only in 1992. The operating license was issued in November 1993 and from this time the reactor has been operated in a regular manner on 10MW nominal power.

The reactor is used for various purposes (e.g. isotope production) but the main user is neutron research. This research possibility was offered to the entire user community of Europe (scientists active in member states and associated states of European Community) within the 5^{th} Framework Programme. Eight instruments for neutron scattering, radiography and activation analyses are offered. The majority of these instruments get a much-improved utilization with the cold neutrons. Commissioning of the cold neutron source (CNS) was finished at the end of 2000.

The CNS sponsored partially by the Copernicus project of the EU and by the IAEA, was installed at a tangential beam port of the reactor and it will extend the use of the reactor, especially in the scientific field. The source is liquid hydrogen type and the relatively low heat load (about 250 W) makes feasible the direct cooling of the condensed hydrogen (average temperature ~20K) in the double walled moderator cell by the cold helium gas. The construction work was completed early 2000, the out of reactor cold tests were performed during the summer shutdown period. With the operating CNS the reactor was first on nominal power on September 27, 2000. Test operation of the CNS was made in the last four reactor cycles of the year 2000, while the licence for the regular operation was issued in January 2001.

2. Description of the CNS

2.1 Cold Plug (Hydrogen System)

The so-called cold plug consists of two main components, which are connected together with a flange (see Fig. 1).

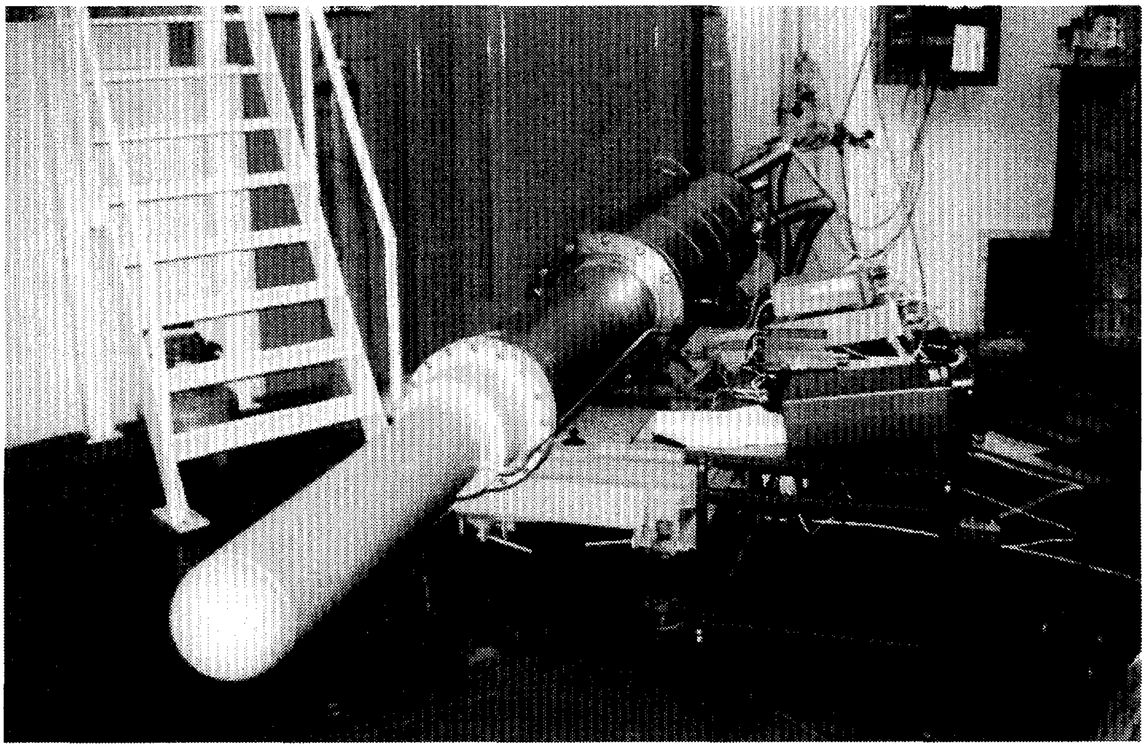

Fig 1. The cold plug in the time of out of reactor tests

The head, which is an explosion-proof vacuum chamber, contains the double-walled moderator cell and it's connecting pipelines. The vacuum chamber is double walled to allow the cooling of the walls.

The moderator cell, is a double walled aluminium structure, having cold helium between the walls and hydrogen inside. When the cold operation starts, the helium first makes the hydrogen liquid, than removes the heat generated in the liquid hydrogen and the walls of the cell. The geometry of the moderator cell allows minimal hydrogen temperature with minimal void. The moderator cell with the direction of the helium flow can be seen in Fig. 2.

The volume of the cell is about half a litre, the initial pressure of the warm hydrogen is 3.5 bara, while the cold pressure of the hydrogen is ~2.7 bara. The moderator cell is connected to a buffer tank via a double walled pipeline. When the hydrogen is condensed, it is supplied from the buffer tank, while warmed up, it is let back to the buffer tank. The hydrogen safety is ensured by a helium blanket around the inner hydrogen pipeline. A valve-box controls the hydrogen system, inside the box (around the pipes and valves also helium blanket ensures the hydrogen safety).

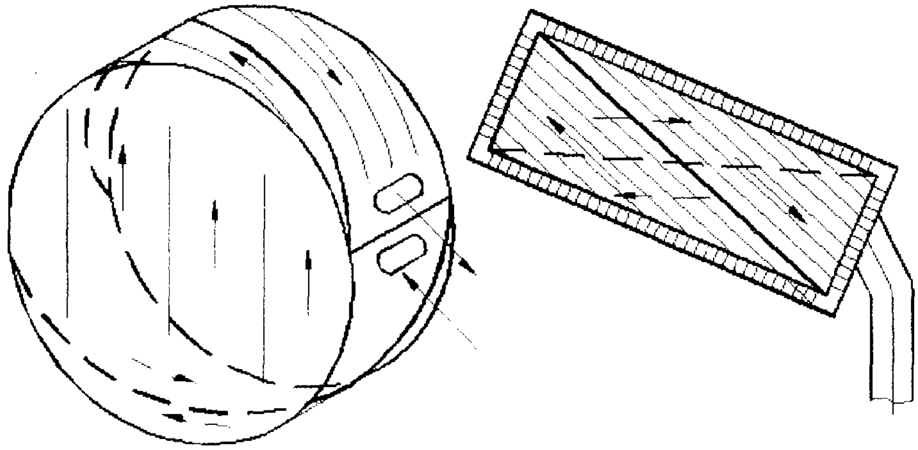

Fig 2. The moderator cell

The cooling capacity and the helium flow rate of the helium refrigerator was determined by an experimental setup. The helium cryogenic-pipeline was connected to an electrically heated box, which imitated the heat load of the cold plug. The in- and outlet temperatures and their difference were measured on-line, on the refrigerator and the experimental setup. The heat removed by the helium gas, is the sum of the heat loss and the electrical heating: $Q = Q_0+Q_{el}$, $Q = C_{pHe}\times G\times \Delta T$, where $C_{pHe} = 5.25$ [J/gK] is the specific heat of helium, G g/s is the mass flow-rate of the helium, while ΔT [K] is the temperature difference:

$C_{pHe}\times G\times \Delta T = Q_0+Q_{el}$
or
$\Delta T = \Delta T_0+Q_{el}/(C_{pHe}\times G)$

The estimated total heat load of the moderator cell at nominal (10 MW) reactor power is: $Q_{Al} + Q_{H2} = 189$ W, while the measured heat loss of the whole system is 52W.

Upon inserting the cold plug into the biological shielding of the reactor cooling tests were performed on various reactor powers (0, 2, 5, 8 and 10 MW). The in- and outlet temperatures and their difference were measured on-line on the refrigerator and the cold plug as it was made in the case of the experimental setup. The results are the following:

Reactor power=0 MW
$\Delta T_0 = 1.85$ [K], $q/G_0 = 1.9$ [J/gMW] (0.36 [K/MW]), $Q_0 = 97$ [W]

Reactor power=10 MW
$Q_{10R} = 189$ [W], while the total heat load is $Q_t = 286$ [W]

This value is somewhat higher than the nominal cooling capacity of the refrigerator, but increasing the hydrogen pressure beyond the design value but within the allowed pressure range, the whole hydrogen content of the moderator cell can be kept in liquid state. In the near future the refrigerator will be adjusted according to the as built state of the system in order to decrease the hydrogen temperature and pressure.

The steel body of the cold plug (see Fig 3) holds the explosion proof vacuum chamber and contains the three neutron guides. The steel body also provides biological shielding and there is a lead beam shutter in its front part, which makes possible the maintenance on the neutron guides and the beam shutters.

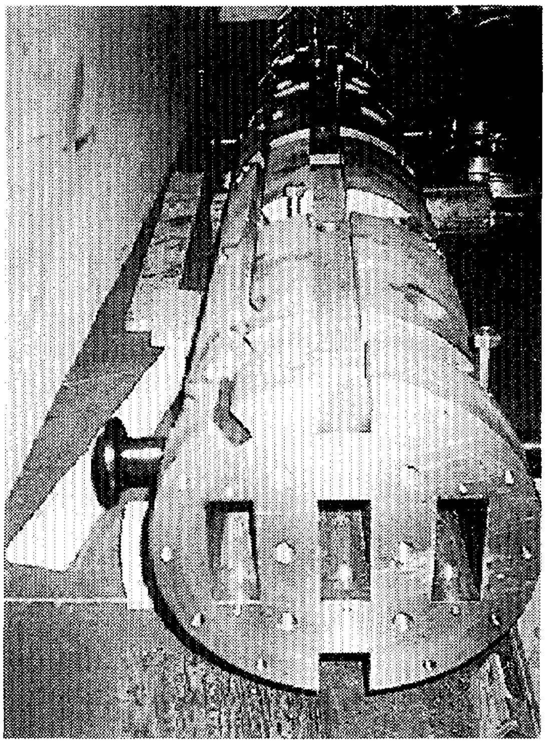

Fig 3. The steel body of the cold plug with the holes of the neutron guides.

The neutron guide system consists of three curved super-mirror neutron guides having different lengths. The first part, which is built in the steel body of the cold plug, is made of a special ceramics, having higher irradiation resistance. The out-of reactor part of the neutron guide is made of boronized glass. The coating is nickel, containing titanium. The first part of the guide (to the beam shutters and one meter after them) is in vacuum jacket. The end part of the guide is vacuumed directly.

The beam shutters ensure the individual closing and opening of the beam ports. The design provides inherent safety, so that the basic position of the shutter is closed. In closed state it is a 50 cm long sandwich structure, containing several layers of boronized polyethylene, steel and lead. The shutter can be opened by compressed air, when a 50 cm long super-mirror neutron guide is lifted into the opening position. In case of emergency the shutter can be closed simply by releasing the air pressure.

2.2 The refrigerator system

The refrigerator system, which was installed in a new building connected to the reactor hall, has the following four major components:

a. / Compressors

Two KAESER type screw compressors can provide 6 g/s and 12 g/s helium flow respectively. When the CNS is operated in cold mode both compressors are running parallel, while in the so-called warm mode the smaller one is enough to cool the moderator cell and the vacuum chamber.

b. / Oil removal system
The built-in filter removes the oil from the helium gas and four pumps (two-two) feed back the oil into the compressors.

c. / Bypass filter
The bypass filter should be used before the CNS cold operation every time when the helium system is opened. The helium gas shall be rotated through the filter until the gas purity measured by a built-in gas analyser reaches the needed value.

d. / Cold box
The cold box is the heart of the refrigerator system. The cooling process is made by two turbine type expanders, which expand the helium gas from 10.5 bar to 1.5 bar pressure. Control of the cooling process is performed by a microprocessor-based controller (PLC), which not only controls the whole system, but also collects and displays the measured data of the system including the valve positions. The operation including the transients, i.e. cooling down and warming up the system are entirely automatic, only the start-up preparations such as gas cleaning and helium filling of the cooling system is made manually. There is a water cooler connected to the cold box to cool the brake gas of the turbines and the diffusion vacuum pump, providing the heat insulation of the cold box.

2.3 Cryogenic pipelines

The cold plug is connected to the refrigerator by cryogenic pipelines. The pipelines are double walled, the insulation of the cold helium pipeline is provided by special heat insulation coating of the inner pipe and by high vacuum made by a turbo molecular vacuum pump.

2.4 High vacuum pipeline

The high-vacuum pipeline is connected to the double walled explosion proof high vacuum chamber providing the insulation of the moderator cell. A helium blanket covers the high-vacuum inner pipe, so in case of a leakage no air can freeze on the surface of the moderator cell and of the connecting pipes. The high-vacuum pipeline is connected to a turbo molecular pump via a valve box containing a helium blanket around the valve.

2.5 Instrumentation and control (I&C)

As it was mentioned, the refrigerator system has a PLC based controller, which controls the refrigerator including the gas management system and the compressors. There is a higher lever controller, which gives orders to the controller of the refrigerator, controls the helium blanket and handles the emergency situations.

Four display and control panels were designed and built in the I&C system:
The first panel is situated in the new refrigerator building. From this building not only the measured parameters of the whole system can be displayed but also all the valves can be manually operated.

The second panel is in the reactor hall. This panel serves only as a display where every measured value can be seen and also contains a data acquisition computer too. No manual control of the valves is possible from this panel.

The third panel is in the control room of the reactor. On this panel the most important measurements are displayed, which inform the operator about the status of the system. The main safety philosophy of the CNS is that the cold source cannot be harmful for the reactor but the reactor can cause damage in the moderator cell and the explosion proof chamber. This is why the CNS measurements are not connected to the reactor safety system, but the operator shall be kept informed about the status of the system. In case of a cooling problem (failure of both compressors) the reactor power should be decreased or the reactor should be shut down.

3. Conclusions

Installation and commissioning of the cold source proved that the inner heat-exchanger concept could be used in those cases where the irradiation heat load is relatively low. The first neutron spectrum measurements showed that the efficiency of the system as a whole (including the new neutron guides and beam shutters) improved by a factor of forty in case of neutron scattering and by a factor of sixty for neutron capture type measurements.