THE FRG-1 COLD NEUTRON SOURCE
- MEASURES FOR HIGH NEUTRON FLUX AND AVAILABILITY –

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1. Introduction

Long wavelength (cold) neutrons with high intensity are indispensable probes for material-, biological- and polymer research. For this reason GKSS installed a cold neutron source (CNS) at the FRG-1 in 1988. Around 60% of all neutron scattering instrumentation are using cold neutrons. Principal component of this CNS is the moderator cell shaped like a discus. As moderator supercritical gaseous hydrogen is applied. With this plant the number of long wavelength neutrons with $\lambda > 0.4$ nm were increased by a gain factor of more than 20.

The long CNS- operational experience led to many plant improvements and thus to an increase of the availability. Examples of these measures are the forced and unforced circulation of the hydrogen moderator and a new two barrier vacuum system for minimizing the faults.

In order to again increase the yield of cold neutrons, a study for a new layout of the moderator chamber was performed. The fundamental new design of the moderator chamber is based on a hemisphere form, thereby increasing the cold neutron flux by approx. 60% exploiting the focusing effects.

The new design doubles the weight of the H_2-moderator, whereas the weight of the structural material (AlMg3) only increases by 10%. However, this total weight enhancement increases the nuclear heating by 2% only. The paper will discuss the new moderator cell design, the nuclear heat density and stability requirements for the shielding walls.

2. Cold Neutron Source (CNS)

2.1 The existing CNS

The CNS installed 1988 possesses a moderator cell shaped as a discus, which is filled with supercritical gaseous hydrogen as moderator (Fig. 1).

Dimensions of the CNS moderator cell	
Large axis	155 mm
Small axis	60 mm
Wall thickness	5.8 mm
Volume	796 cm^3

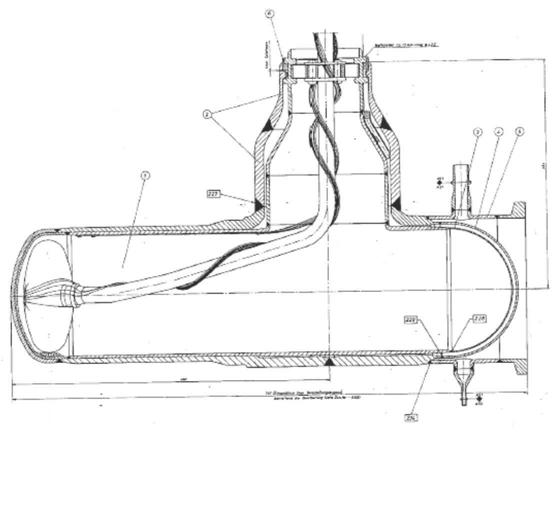


Fig. 1: In-pile Section of the existing Cold Neutron Source

The moderator cell is manufactured from AlMg3 meeting the following specifications: At normal operating conditions to generate cold neutrons the moderator has a temperature of $T \approx 25K$ and a pressure $p \approx 15$ bar, respectively. A He-refrigerator with an inlet-/outlet-temperature of 19K/30K is used to provide these low temperatures. The heat generated by the nuclear heating of the hydrogen of approx. 1400 W plus the heating of the cold structure of approx. 250 W are dissipated at the H_2/He heat exchanger (Fig. 2). Besides the forced H_2-circulation, which cools the moderator cell at all operational states of the reactor, it is also possible to cool the moderator cell by natural convection.

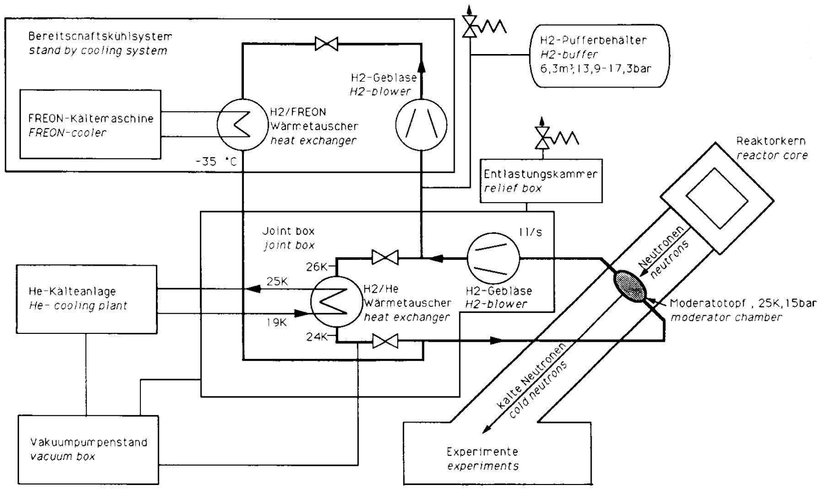


Fig. 2: Schematic View of the GKSS – CNS

Should the He-cooling system fail, a standby cooling system is available. This Freon cooling system supplies temperatures of –35°C. No cold neutrons are produced any more, but nevertheless the reactor can be operated. The GKSS-CNS as existing delivers a gain factor for cold neutrons of more than 20 for long wavelength neutrons and is well comparable to other CNS.

2.2 CNS Upgrades

In the past a frequent failure of the CNS was caused by the bearing damage of the blower for the forced H2 – circulation. During such provident switch off, we observed that the CNS remains under normal operation condition, which means a moderator temperature below 35 K (see Fig. 3). An explanation for this surprising phenomena is a stable natural convection of the H2 moderator. In the case of natural convection, the driving pressure difference for the H2-circulation is given by:

$$\Delta P = \Delta \rho * g * \Delta h$$

The difference of the altitudes between moderator chamber (source of heat) and heat exchanger is Δ h = 4.3 m. Just so a great difference of altitudes and temperature (inlet/outlet) yields a high driving pressure difference which is necessary for the natural convection /1/.
Further we had taken better bearings for the H2 – blower. Thus the periods of operation increased from approx. 3 month to over 2 years.

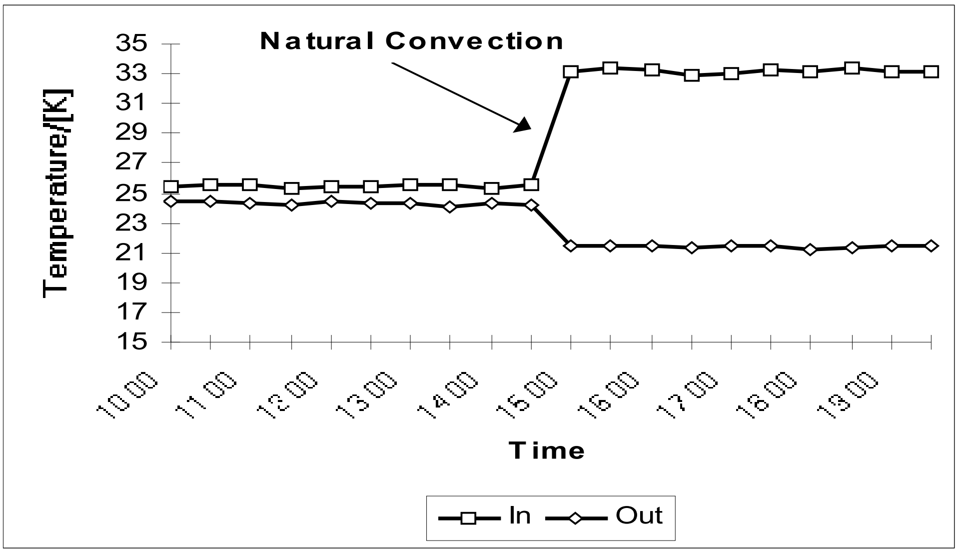


Fig. 3 Moderator inlet and outlet temperature

A further breakdown was due to a failure of the vacuum pumps (ionic getter pumps). These pumps are part of the triple containment of the hydrogen inside the building (H2-circuit, vacuum system, outer barrier). For this reason a new vacuum system was designed. In place of the getter pumps, which are surrounded by a He - atmosphere, turbo-molecular pumps were used. These new vacuum components were enclosed by a new barrier with a nitrogon atmosphere (Fig. 4). Also we have changed the CNS protection system.
These measure (nature convection, blower bearings, vacuum system) led to a drastic improvement of the CNS periods of operation.

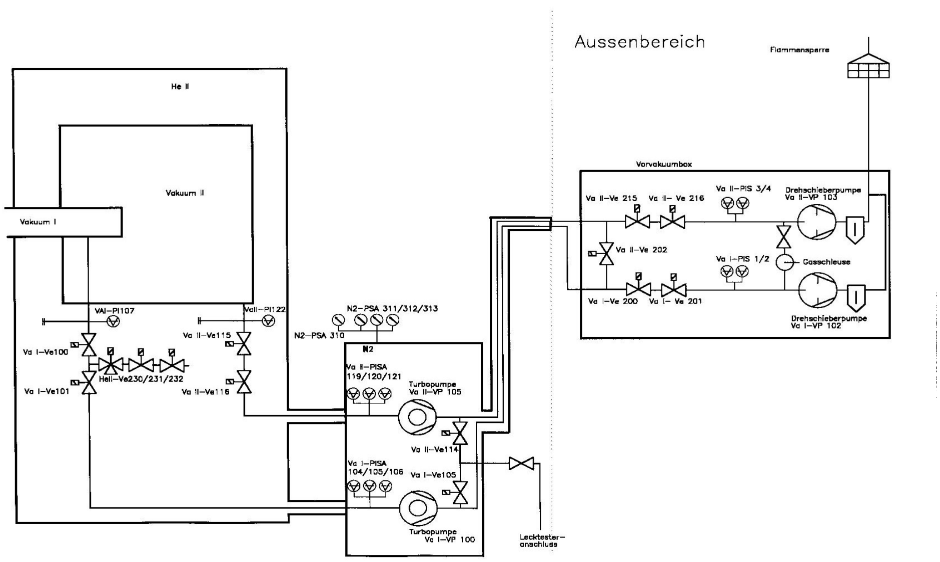


Fig. 4a: Schematic drawing of the new Vacuumsystem

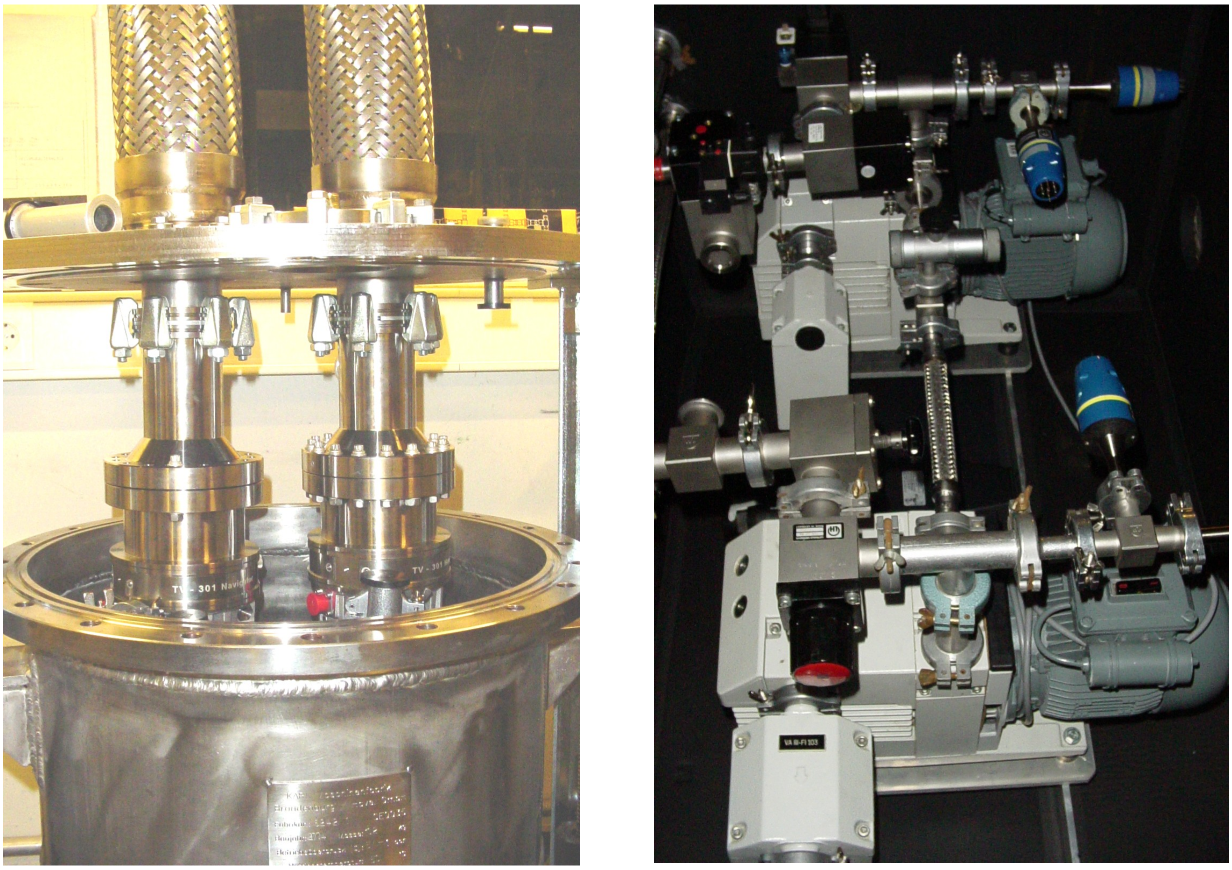
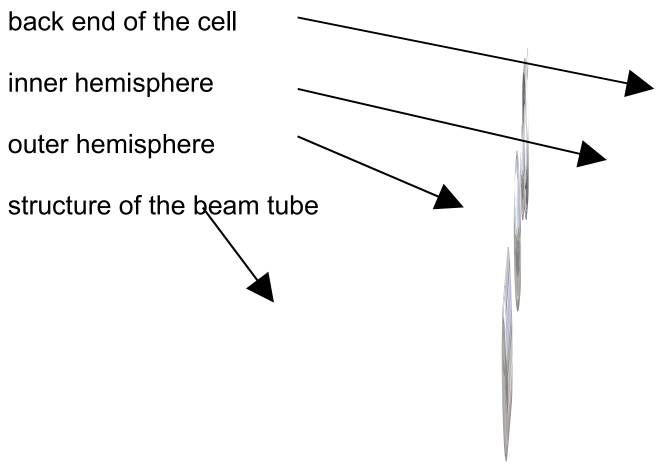


Fig. 4b: Turbo-molecular pumps and rough pumps

2.2 The new moderator cell design

A study was ordered from Framatome for an innovative design of the moderator cell to optimise the cold neutron flux even further. An important parameter under investigation was the moderator thickness in direction of the beam tube. That thickness must enable sufficient moderation of the neutrons down to the temperature of the moderator atoms ($T \approx 25K$). At the same time the absorption of cold neutrons must not increase strongly. These competitive processes are to be considered particularly with H_2 as moderator in terms of a careful optimisation of the moderator thickness.

The neutronics design and optimisation was accomplished with the 3D Monte Carlo Code MCNP. The basic geometry of the moderator cell consisted of two parallel hemispherical shells and two concentric cylinders (Fig. 5). The distances of the hemispherical shells and of the cylinder barrels varied. That basic design was selected also due to its mechanical stability by balls and cylinders so that relatively thin walls could be taken. In this way the parasitic heating in the structure material could not rise excessively. Calculations for the improved performance of the CNS were performed for different distances. The accomplished part of the neutron flux densities at the neutron guide entrance, which had angels permitting total reflection at the guide walls, were compared with that part at the existing design. For the moderator cell an convincing gain factor of up to 60% results due to the focusing effects of the new shape of the moderator cell (Fig. 6).



Dimensions of the new moderator cell	
Outer radius of hemisphere	84 mm
Inner radius of hemisphere	51 mm
Wall thickness	3 mm
Volume	1560 cm^3

Fig. 5: 3dim. drawing of the new moderator cell

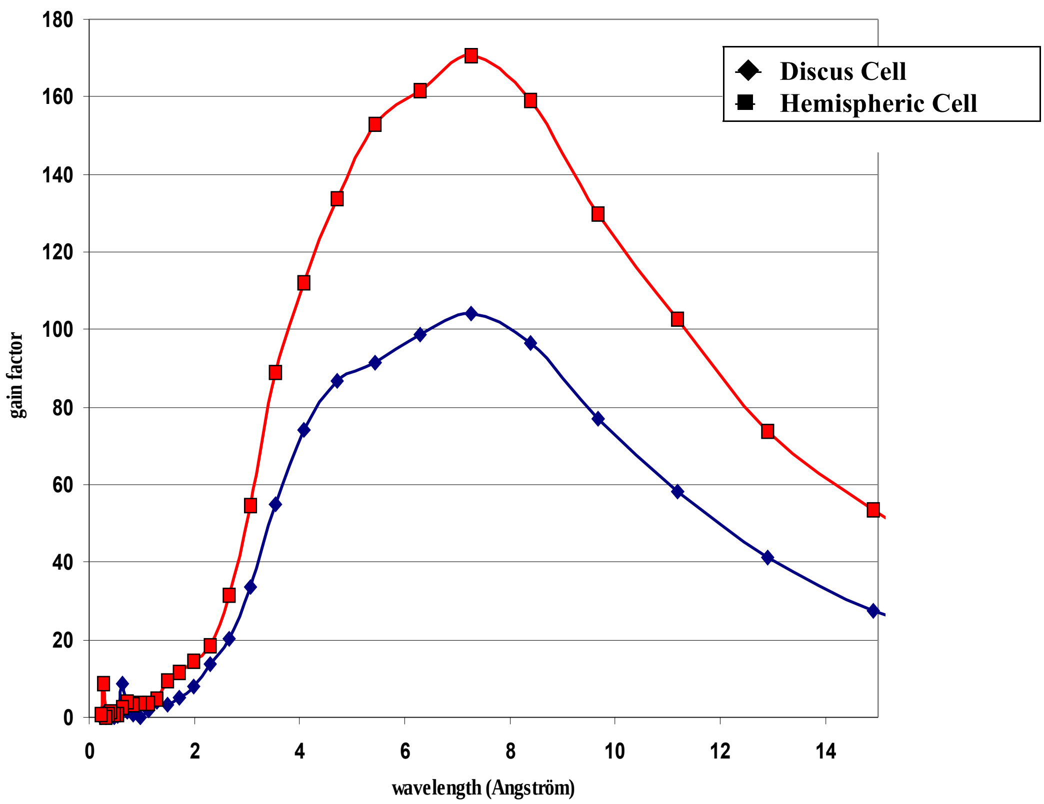


Fig. 6: Comparison of neutron spectra with discus and hemispheric cell

The volume and mass of the moderator and structural material are essentially responsible for the nuclear heating. In Table 3 the appropriate parameters of the existing discus shaped cell and the focusing hemispheric cell are compared. The most important result of the heat-density-calculation is the small increase of the nuclear heating of approx. 25 W only. This additional heat can be dissipated easily with the existing refrigerator plant with a maximal cooling power of 200 W.

	Discus Shaped Cell			Hemispheric Cell		
	Volume [cm^3]	Mass [g]	Heat [W]	Volume [cm^3]	Mass [g]	Heat [W]
Moderator H_2	796	55	353.8	1560	107.5	499
AlMg3	298.6	788.4	998.4	351.5	928	878
$\sum$			1352.2			1377

Tab.3: Parameters of the discus shaped cell and hemispheric cell

The very promising and positive results obtained from the study in terms of gain factor and nuclear heating will lead to the replacement of the present moderator cell by a focusing-one.

3. Summary

The consistent increase of the neutron flux by two core compactions and by the installation of the CNS was already realised by GKSS /2/. The installation of the focusing moderator cell will lead to a further increase of the important cold neutron flux. The additional gain of cold neutrons of approx. 60% will lift the FRG-1 to an interesting neutron source for the national and international user community. Along with the continuous upgrades and refurbishment in the past this major improvement is the best guarantee for the future operation of FRG-1 for n-scattering and irradiation experiments during the next decade.

/1/ W. Knop and W. Krull; The Cold Neutron Source of GKSS, atw, 43. Jg. (1998), Heft 2-Februar

/2/ W. Knop, W. Jager and P. Schreiner; FRG-1 Compact Core with Higher Density Fuel, RERTR, Bariloche, November 2002