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STATUS REPORT ON THE COLD NEUTRON SOURCE OF THE GARCHING NEUTRON RESEARCH FACILITY FRM-II

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Abstract

The new high flux research reactor of the Technical University of Munich (Technische Universität München, TUM) will be equipped with a cold neutron source (CNS). The centre of the CNS will be located in the D2O-reflector tank at 400 mm from the reactor core axis, close to the thermal neutron flux maximum. The power of 4500 W developed by the nuclear heating in the 16 litres of liquid deuterium at 25 K, and in the structures, is evacuated by a two phase thermal siphon avoiding film boiling and flooding. The thermal siphon is a single tube with counter current flow. It is inclined by 10° from vertical, and optimised for a deuterium flow rate of 14 g/s.

Optimisation of structure design and material, as well as safety aspects will be discussed. Those parts of the structure, which are exposed to high thermal neutron flux, are made from Zircaloy 4 and 6061T6 aluminium. Structure failure due to embrittlement of the structure material under high rapid neutron flux is very improbable during the life time of the CNS (30 years). Double, in pile even triple, containment with inert gas liner guarantees lack of explosion risk and of tritium contamination to the environment.

Adding a few percent of hydrogen (H2) to the deuterium (D2) will improve the moderating properties of our relatively small moderator volume. Nearly all of the hydrogen is bound in the form of HD molecules.

A long term change of the hydrogen content in the deuterium is avoided be storing the mixture not in a gas buffer volume but as a metal hydride at low pressure. The metal hydride storage system contains two getter beds, one with 250 kg of LaCo3Ni2, the other one with 150 kg of ZrCo(0.8)Ni(0.2). Each bed can take the total gas inventory, both beds together can absorb the total gas inventory in less than 6 minutes at a pressure < 3 bar.

The new reactor will have 13 beam tubes, 4 of which are looking at the cold neutron source (CNS), including two for very cold (VCN) and ultra-cold neutron (UCN) production. The latter will take place in the horizontal beam tube SR4, which will house an additional cryogenic moderator (e.g. solid deuterium).

More than 60% of the experiments foreseen in the new neutron research facility will use cold neutrons from the CNS.

The mounting of the hardware components of the CNS into the reactor has started in the spring of 2000. The CNS will go into trial operation in the end of year 2000.

Introduction

Modern research reactors should provide neutron beams not only in the thermal neutron energy range but also mainly in the cold neutron energy range (E < 10 meV). At the Munich Research Reactor II (FRM-II) more than 50 % of all beam positions will use cold neutrons.

Here we report on the features and the status of the "big" cold neutron source (CNS) for the FRM-II under construction. The basic design of this CNS has been presented at previous IGORR meetings. For a report on a "mini D2 UCNS" and further papers related to FRM-II see /1/.

Features of the CNS

Tab. 1 summarises the essential data of our CNS as compared with the CNS of the old Munich Research Reactor FRM, and with the vertical ("reference") CNS at ILL Grenoble (in its 1985 version).

The integral cold neutron flux in our CNS will be comparable to that in the vertical one at ILL although the ILL reactor runs at a power nearly three times as high. This is possible because :

the core of the FRM-II is light water cooled and more compact

the axis of the CNS is much closer to the core

the flux depression in the CNS due to voids is less

the cooling power needs can be kept small by reducing size and wall thickness of the CNS.

The centre of the CNS is so close to the core that the cold moderator volume is partly located in the thermal neutron flux maximum. At this location the epi-thermal and fast neutron flux is considerable, in spite of the light water cooling of the core. The moderator fluid therefore has to absorb a high specific heat load of up to 4 W/g, leading to a high bubble content and a strong internal fluid circulation.

In order to keep the refrigeration needs below 5 kW, the mass of the cold moderator fluid has been limited to 2000 g, of which about 100 g will be hydrogen, the rest deuterium (D2). This is a possible mixture to adapt the mean free path of the neutrons to the vessel dimensions. The optimum concentration of hydrogen will be determined during the first tests with reactor power.

Although the total integral neutron flux in the CNS is about the same as at the ILL vertical CNS, the spectral distribution will be much flatter between 1 and 4 Å, emphasising the thermal part of the spectrum (Fig.1). This can be of some advantage for cold neutron users.

In spite of the fact that nowadays very exact and detailed data for zircaloy are available /2/, the lack of knowledge about the hydrogen diffusion into zircaloy under radiation at low temperature, and consequently about the risk of embrittlement in a zircaloy wall of the moderator cell, led to the decision to use the aluminium alloy Al-6061 T6 instead. This strong alloy shows no important embrittlement during the projected life time of our reactor. A mean wall thickness of only 1 mm is sufficient for withstanding a 6 bar overpressure inside the moderator cell.

During a normal operation cycle the maximum overpressure in the deuterium system should not occur when the moderator cell is warm. This will be achieved by chemically storing the warm moderator fluid (gas) as a metal hydride in two getter beds, one containing 250 kg of LaCo3Ni2, the other one 150 kg of ZrCo(0.8)Ni(0.2). The D2 storage capacity is about 1 to 2 %weight, depending on the pressure. Each getter bed can store the total inventory of gas on its own.

Additional advantages of such a metal hydride storage system :

the total deuterium inventory is only about 60 % of a CNS with gas buffer

during reactor stop the in-pile system is always empty of hazardous gas

the whole (later tritium-activated) gas inventory can be shipped as compact solid nuclear waste for retreatment or underground storage

the isotopic mixture does not change its concentration with time due to fractional distillation, because there is no buffer volume.

The vacuum vessel of the in-pile part will be made from zircaloy, the moderator cell and tubing from the aluminium alloy 6061 T6. The insert, which optimises the geometry of the cold moderator volume, will be made from magnesium. The deuterium condenser has a 10 m^2 heat-exchanger area made from aluminium tubing. Bi-metallic junctions (Al/stainless steel) are used at the 25 K level in different places to take advantage for thermal insulation from the low thermal conductivity of the stainless steel. The in-pile part will be connected to the gas handling system via flexible stainless steel tubing throughout in order to guarantee vibrational decoupling of the in-pile part to the rest of the reactor building in case of an external shock (e.g. earth quake or air craft accident).

The main feature of the gas handling system is the double containment of deuterium throughout. All vessels and tubes, including the metal hydride storage tanks, which do (or could eventually) contain D2, are surrounded be at least one envelope containing pure nitrogen as an inert gas at a pressure slightly higher than ambient. Such a system allows a continuous leak testing and makes impossible the build-up of an (explosive) D2-air mixture. Also, the vacuum exhaust pipes are connected to a tritium monitor to detect traces of (later activated) D2 which could have leaked into the insulation vacuum.

The refrigerator has to move 5 kW of nuclear radiation heating away from the cold source at the 25 K temperature level. It can be upgraded to 8 kW refrigeration power by adding an extra compressor and further expansion turbines, in case of additional needs of refrigeration near the reactor core (e.g. for a second CNS). The actual compressor will need about 500 kW of electrical power to deliver about 300 g/s of helium at 16 bar.

Status of the CNS construction

Monte Carlo simulations with the MCNP-4A codes to optimise the moderator shape and position, and to estimate the heat load, have been completed /3/. The general contractor, Linde AG, Germany, is now responsible for the construction of the 4 main components of the CNS, i.e. the in-pile part, the gas handling, the metal hydride storage system, and the refrigerator. Main subcontractors are ACCEL GmbH for the in-pile part, HYCOB GmbH for the metal hydride storage system, and Linde Kryotechnik (CH) for the refrigerator.

Two rooms on the 11.70 m floor of the reactor building are dedicated for the CNS cold box, gas handling and control desk. Additional floor space is foreseen inside and near the compressor building. All the buildings are erected now, and the mounting of the hardware has completed. First test operation is due in November 2000.

References

/1/:Altarev, I., F.J. Hartmann, S. Paul, W. Schott, C. Seidel, and U. Trinks :
"A solid-deuterium source of ultra-cold neutrons at the FRM-II"
IGORR 7 Meeting (1999), Argentina

/2/:Scheuer, A., and E. Gutsmiedl : "Use of Zircaloy 4 material for the pressure vessels of cold and hot neutron sources and beam tubes for research reactors"
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3/:Gaubatz, W., and K. Gobrecht "The FRM-II Cold Neutron Source" Proc. European Neutron Scattering Conference (ECNS2) Budapest Sept.1999

Tab.1
FRM Cold Neutron Sources : essential characteristic data

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	FRM	FRM-II	ILL vertical CNS	units
Nominal reactor power	4	20	57	MW
Integral neutron flux in CNS	$2 \cdot 10^{13}$	$4 \cdot 10^{14}$	$4 \cdot 10^{14}$	$cm^{-2}s^{-1}$
Distance from core (axis to axis)	300	400	760	mm
Specific heat load at hot point / on axis	0,3/0,1	2.6/1.2	1/0,5	W/g
Size of the moderator cell	146x250	Ø300x240	Ø360	mm
Material of the moderator cell	AlMg(3)	Al 6061	Al (99.5)	%
Moderator cell : mean wall thickness	1	1.0	1.8	mm
Volume of the moderator cell / insert	0.9	20 / 6	24 / 4,5	litres
Moderator fluid	H_2	D_2+(5%)H_2	D_2	liquid
Mass of H_2/D_2 in the moderator cell	65	2000	3000	g
Temperature of the cold moderator	18	25	25	K
Pressure in the cold moderator	3.5	150	150	kPa
Pressure in the warm H_2/D_2-system	4.5	~0	300	kPa
Expected refrigeration power	400	5000	6000	W
Hydride forming time (for 95 % D_2)	N/A	6	N/A.	min.
Volume of the gas buffer	7.5	15 1)	18	m^3
Number of tubes in the thermal siphon	2	1	3	
Material of the in-pile vacuum thimble	AlMg(3)	Zry	Zircaloy (Zry)	
Mean wall thickness of the thimble	10	4	6	mm
Vertical beam tubes for VCN/UCN	0	1	1	
Horizontal beam tubes	1	3	1	
Horizontal cold guides or collimators in-pile	1	10	5	

1) used only for emergency

Fig. 1

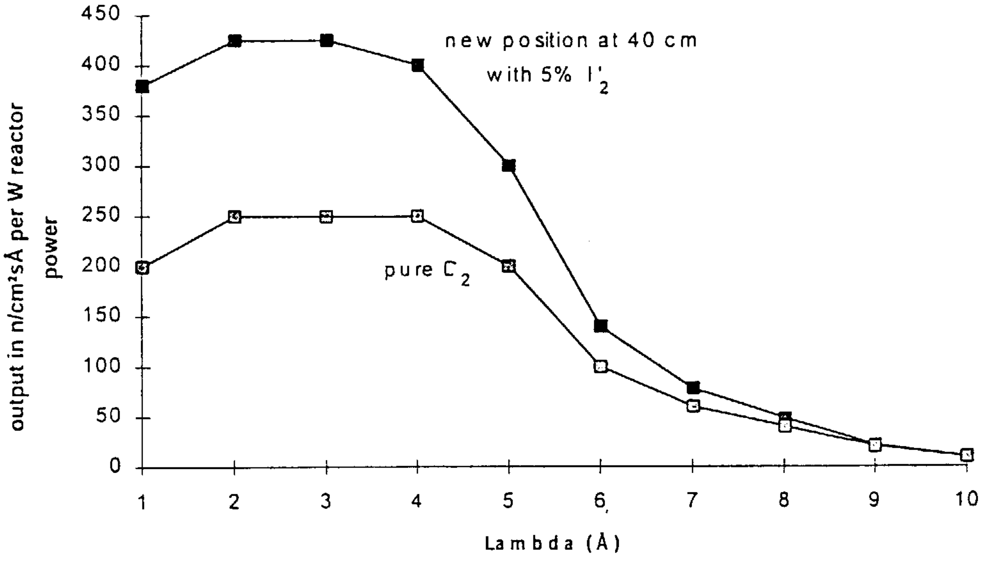

Fig. 1 : Cold Neutron Source FRM-II :
Neutron Flux at a Point Detector in the Beam Tube at 4m.