International Group On Research Reactors
6th Meeting in Taejon/Korea, Apr.1998

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

presented by

Klaus GOBRECHT

Technische Universität München

TOPICS

- Recall of the main characteristics of the FRM-II Cold Source
- Cold neutron output vs. heat load optimisation
- New features in cooling power- and gas-handling
- Projected utilization of cold neutrons at FRM-II

FRM-II CNS

The FRM-II (Forschungsreaktor München-II) in Garching will be a 20 MW reactor with H_2O cooling, D_2O moderation and a relatively small fuel element with highly enriched uranium (HEU 93 % enrichment). With such an optimized design an "unperturbed" thermal neutron flux of $8 \cdot 10^{14}/cm^2 \cdot s$ can be obtained with low power and small amount of radioactive waste. The FRM-II will become operational in the year 2002, and then be the strongest neutron source in Germany and one of the most attractive in Europe.

The FRM-II will be equipped with a vertical CNS, a second one is projected to be horizontal.

(Fig.1)

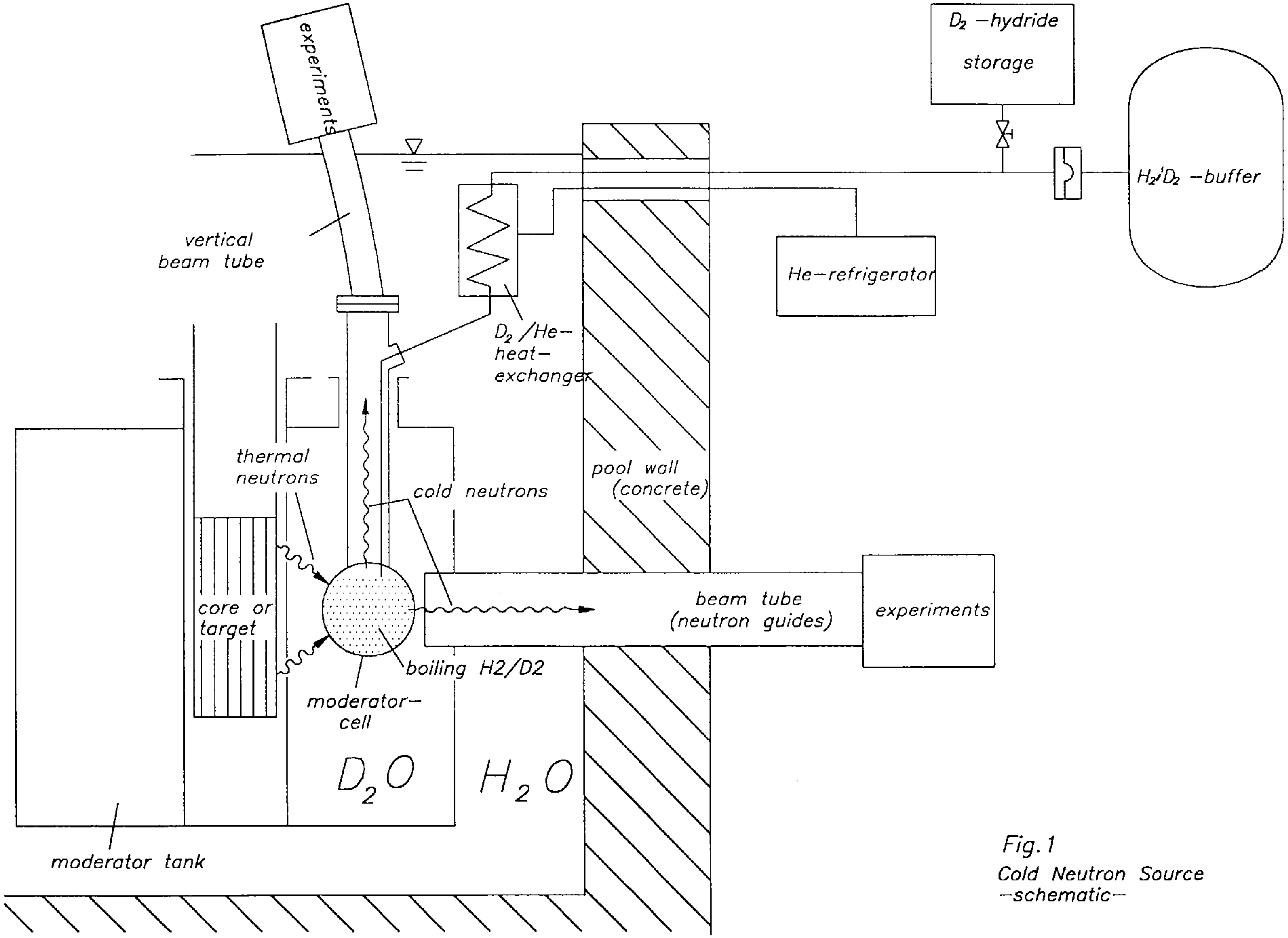

Fig. 1
Cold Neutron Source
–schematic–

FRM-II CNS (2)

The vertical CNS will work with boiling **deuterium** (D_2) at 25 K and 150 kPa, or with a **mixture** of deuterium and hydrogen (<10%) at the same pressure. The moderator fluid serves itself as the heat transfer medium, taking the heat away from the moderator volume to the heat exchanger in a two-phase flow driven by natural convection. The cold moderator cell is a 300 mm diam. cylinder with elliptical bottoms, made of Zircaloy. Its wall is shaped in the form of a re-entrant hole facing beam tubes 1 and 2. The liquid deuterium content is about 16 liters.

(Tab.1), (Fig.2)

Tab.1

FRM Cold Neutron Sources : essential characteristic data

	FRM	**FRM-II**	**ILL vertical CNS**	units
Nominal reactor power	4	20	57	MW
Integral neutron flux in CNS	$2{\cdot}10^{13}$	$4{\cdot}10^{14}$	$4{\cdot}10^{14}$	$cm^{-2}s^{-1}$
Size of the moderator cell	146x250	300 Ø	360 Ø	mm
Material of the moderator cell	AlMg(3)	Zry	Al (99.5)	%
Moderator cell : mean wall thickness	1	0.5	1.75	mm
Volume of the moderator cell	0.9	20	24	liters
Mass of H_2/D_2 in the moderator cell	65	2100	3000	g
Distance from core (axis to axis)	300	400	760	mm
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 - or D_2-system	4.5	~0	300	kPa
Expected refrigeration power	400	5000	6000	kW
Hydride forming time (for 95 % D_2)	N/A	6	N/A.	min.
Volume of the buffer	7.5	10	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	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	

FRM-II CNS (3)

The axis of the moderator cell is 400 mm away from the reactor core axis, and the closest point of the cell lies only 110 mm away from the core. We therefrom expect intensities in the cold neutron beams comparable to those of the high-flux reactor at the ILL in Grenoble (typically $5 \cdot 10^9$ /cm$^2 \cdot$s). The heat load from nuclear radiation emanating from the core onto the cell and from neutron activation is estimated to 5 kW, leading to a D_2-evaporation rate of more than 15 g/s.

In order to limit the heat load on the plumbing, a single, "heat-pipe"-like transfer tube links the moderator cell to the heat-exchanger condenser 4 m above. The tube is inclined by about 10°.

(Tab.1), (Fig.3)

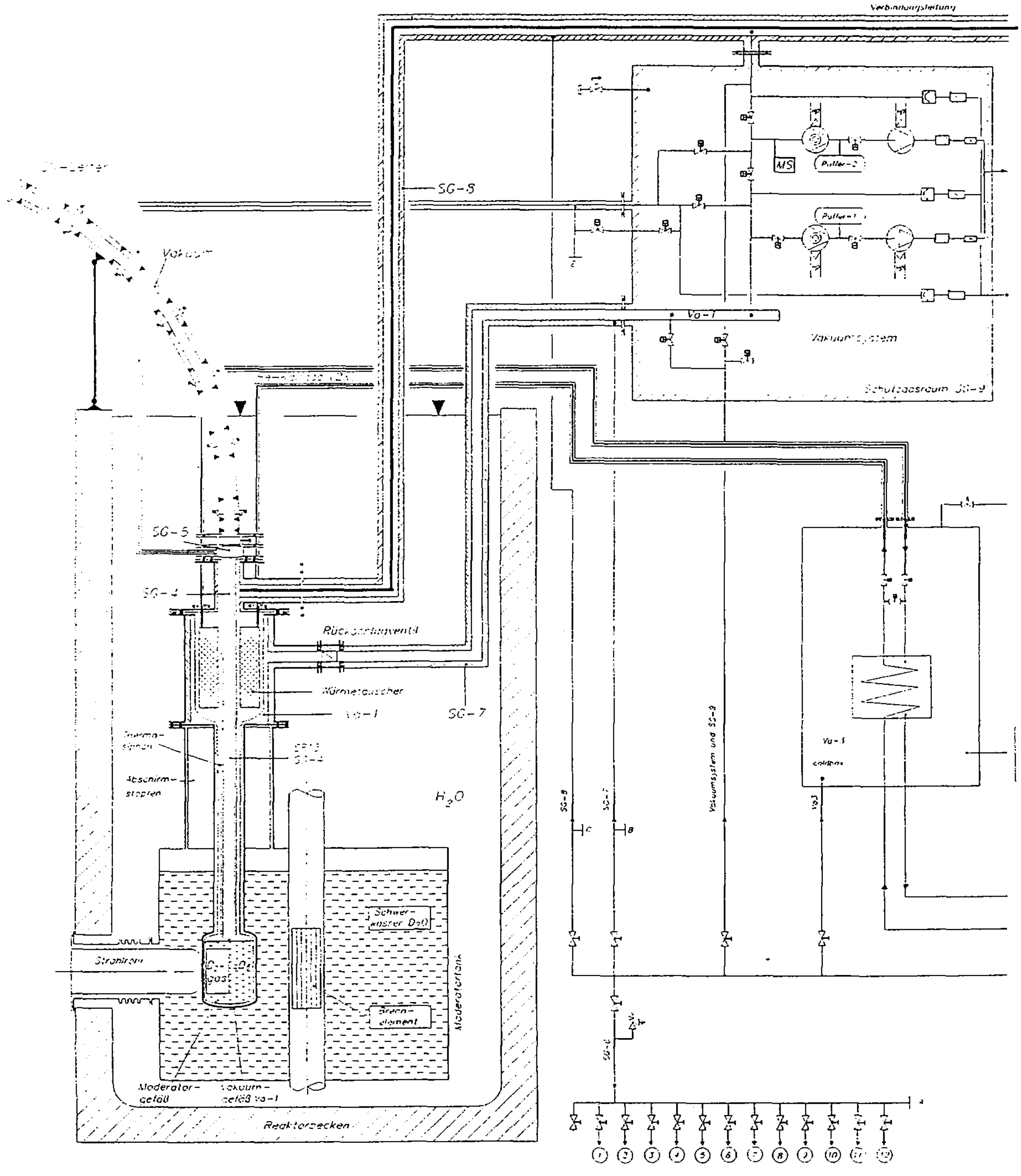

Fig. 3 : FRM-II CNS : in-pile- and vacuum circuits

The Cold Neutron Flux

Monte-Carlo-simulations have been made with **MCNP** (version 4A). The simulations give the spectral distribution of the neutron flux, the brilliance of the CNS, and the heat load on the CNS. The calculations show that the moderator cell as designed, when filled with pure liquid D_2, is too small to give the optimum moderation for wavelengths above 4 Å. By adding a few percent of **hydrogen** to the D_2 one can adapt the neutron mean free path to the cell dimensions. A neutron flux increase of 30 % from 6 to 20 Å is expected. (Fig.4)

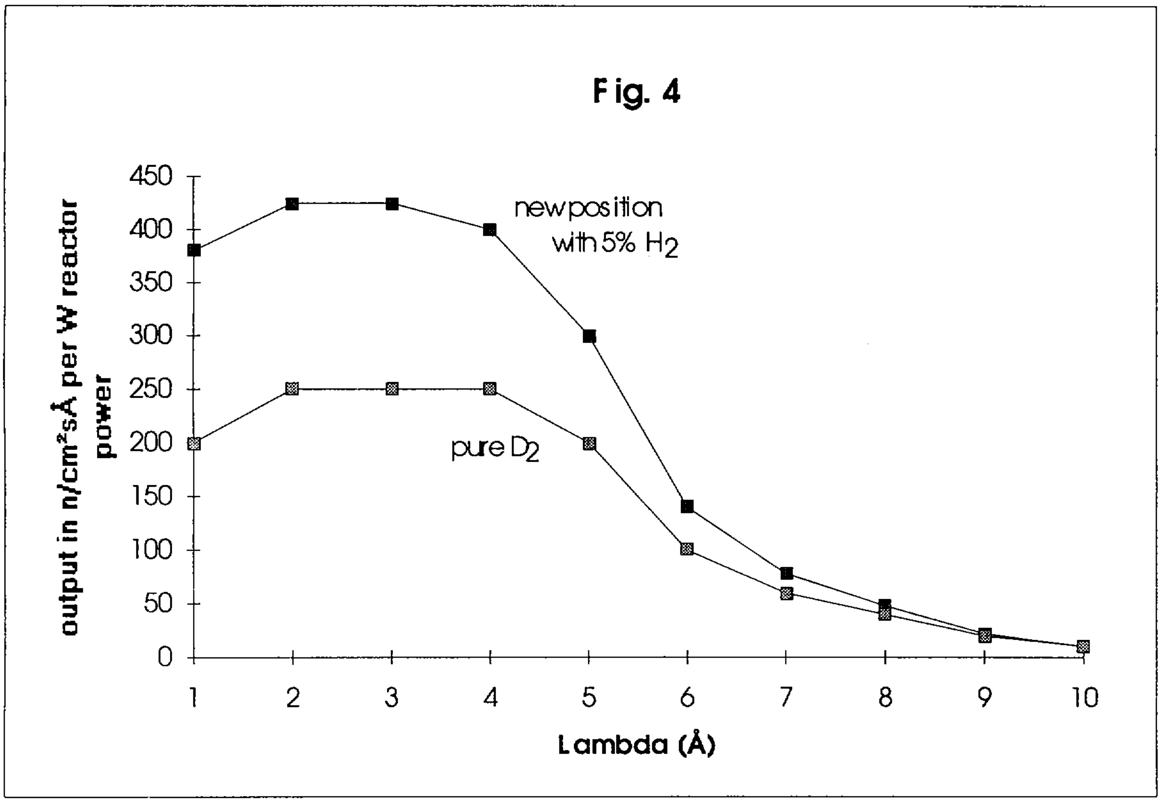

Fig. 4 : CNS FRM-II : Gain in cold neutron output by adding a few percent of H_2 to the D_2

Gas Handling

The deuterium is completely sealed in a double-walled stainless steel circuit. When it is not liquid, it will be stored as a **metal-deuteride** in two tanks containing about 400 kg of a special hydride-forming alloy (e.g. $LaCo_3Ni_2$). Then the residual pressure in the cell and in the plumbing is <10 Pa. For the condensation of the D_2 into the CNS the tanks have to be heated to desorb the gas from the metal-deuteride. In the neutron flux deuterium becomes radioactive by neutron capture (deuterium + neutron => tritium, and tritium => ^{3}He + ß-). After several years of operation the storage tanks will be used to ship the radioactive metal deuteride to a reprocessing plant with-out any risk of contamination.

The out-of-pile parts of the D_2 circuit are protected from D_2-air explosion risk by an **inert gas liner** (nitrogen) pressurized to slightly above atmospheric pressure.

(Fig.1)

Materials

Aluminum and its alloys have the favour of most CNS designers. The capture cross-sections for neutrons and gammas are low, embrittlement is tolerable. β-heating from aluminum activation, however, increases the heat load, and the softening of the material at higher temperatures may cause a problem. Both disadvantages can be avoided by using a reactor grade zirconium alloy, like Zircaloy. Zircaloy shows embrittlement also, in contact with hydrogen, but only at high temperatures and high pressures. The use of the hydride storage system makes it possible to have always a low hydrogen pressure in the moderator chamber when it is warm.

Projected utilization of cold neutrons at FRM-II

Beam tubes SR-1, SR-2, SR-4, and SR-13 look onto the cold source.

SR-1 will contain 6 neutron guides, which go into the neutron guide hall.

SR-4 is now projected to contain an UCN-source with a neutron storage bottle.

(Fig.5)

Tab. 2

FRM-II : beam tube repartition

SR 1	**CNS**	(6 neutron guides -> guide hall)
SR 2 + 4	**CNS**	(4 neutron guides -> reactor hall)
SR 3	**thermal**	(2 neutron guides -> reactor hall)
SR 5	**thermal**	(2 neutron guides -> reactor hall)
SR 6	tangential for fission product accelerator	
SR 7 + 8	**thermal**	(4 neutron guides -> reactor hall)
SR 9	**HNS**	(2 neutron guides -> guide hall)
SR 10	^{235}U converter for fast neutron therapy	
SR 11	**thermal**	(inclined for spectroscopy)
SR 12	**thermal**	(inclined for positron source)
SR 13	**CNS**	(vertical for VCN and UCN)
SDA	**thermal**	(silicon doping facility)