ENGINEERING PROGRESS OF CNS CONCEPT IN HANARO

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ABSTRACT

The Korea Atomic Energy Research Institute(KAERI) strives to provide utilizing facilities on and around the Hanaro reactor in order to activate advanced researches by neutron application. As one of the facilities to be installed, the conceptual design work of CNS was started in 1996 with a project schedule of 5 years so that its installation work can be finished by the year 2000. And the major engineering targets of this CNS facility are established for a minimum physical interference with the present facilities of the Hanaro, a reach-out of very-high-gain factors in the cold neutron flux, a simplicity of the maintenance of the facility, and a safety in the operation of the facility as well as the reactor. For the conceptual design of Hanaro CNS, the experience of utilization and production of cold neutron at WWR-M reactor Gatchina, Russia has been used with that of elaborations for PIK reactor in design for neutron guide systems and instruments.

1. INTRODUCTION

CNS of Hanaro was originally designed and shaped to accommodate the Orphee-typed CNS concept that is a vertical shape of cold moderator system in the reactor pool and a hydrogen cryostat system in the sub-pool, however, the CNS site did not follow the exact shape of the Orphee one. For example, there is no sub-pool in the Hanaro. Consequently, some special concept of CNS must be developed for protecting the reactor core from explosion of H_2-O_2 in case that the condenser or heat exchanger may be installed near the core in the reactor pool.

At the beginning of the conceptual design of CNS, the Orphee type or JRR-3M type of CNS were intensively reviewed for the adaptation into the Hanaro, and as a result significant physical modifications were needed to accommodate them into the Hanaro, meaning that very serious licensing problems may be occurred due to the change of a reactor safety concept.

As a suitable concept to Hanaro, a sub-cooled cold moderator system which is composed of liquid mixtures of hydrogen and deuterium is considered. Because there is no phase change in the sub-cooled system, the facility volume can be reduced so that the sub-pool for installing the condenser of two-phase flow thermosiphon system will not be necessary. Moreover, according to research results from PNPI in Russia, sub-cooled moderator mixtures have a good performance of gathering high-gain factors in a cold neutron. During the course of a conceptual design, we are going to assess the technical possibility of whether the cell and heat exchanger of cold moderator could be included in one vacuum containment. The length of this containment is estimated to be about 2 m, and for its outside diameter, less than 16 cm. The half of its total length will be inserted into the vertical hole, which is reserved for CNS in the reflector tank of the Hanaro with the inside diameter of 16 cm. A thermal neutron flux(<0.625 eV) in the hole is average 10^{14} $n/cm^2 \cdot sec$.

The geometry and composition will be reviewed regarding interference with the existing Hanaro, and calculation of gain factor and heat load will be included in the conceptual design. The main points of the conceptual design include the followings:

- Heat release
- Design of cold neutron source
- Design of ultra-cold neutron source
- Liquid hydrogen loop
- Safety consideration
- Neutron guide system
- General scheme

2. DESIGN DATA AT HANARO

2.1 Basic Data

Hanaro is the open-tank-in-pool type which has benefit of free access to pool top and large inventory of water as heat sink. The reactor pool has dimensions 4 m diameter and 13.4 m height. The reflector tank of 2 m diameter and 1.2 m height contains heavy water and accommodates 25 vertical holes and 7 horizontal tubes. The cold neutron source will be placed into one of the vertical holes in the reflector tank. The diameter of the vertical hole for CNS is 16 cm, its length is 120 cm. The horizontal tube is used for extracting cold neutrons. It is connected with the vertical tube. Nose dimension of the horizontal tube at contacting point to vertical hole is 6x15 cm. The neutron and gamma fluxes at the nose connection point of horizontal tube to vertical hole are shown in Table 1 and Table 2 respectfully.

Table 1

Neutron Fluxes at Hanaro

Energy Level	Neutron Fluxes($n/cm^2 \cdot sec$)
Fast E>0.82 MeV	1.3×10^{12}
Thermal E<0.625eV	1.7×10^{14}
Thermal Flux at Tube Nose	9.7×10^{13}

Table 2

Gamma Fluxes at Hanaro

Energy Level(eV)	Gamma Fluxes($\gamma /cm^2 \cdot sec$)
1.0×10^{-5} to 1.0×10^{5}	5.818×10^{13}
1.0 x 105 to 5.1×10^{5}	4.452×10^{13}
5.1×10^{5} to 6.0×10^{5}	5.610×10^{11}
6.0×10^{5} to 1.3×10^{6}	3.993×10^{12}
1.3×10^{6} to 1.3×10^{6}	5.287×10^{12}
3.0×10^{6} to 7.5×10^{6}	1.286×10^{12}
7.5×10^{6} to 1.4×10^{7}	4.544×10^{10}

2.2 Design requirement

The design criteria for Hanaro CNS is maximum increase and stable supply of cold neutron flux, and safety with regard to personnel and the reactor. High technology for cryogenics and gas explosion and reactor safety engineering is required in design, construction and operation for safety of CNS system and the reactor. Especially, the measure to control the hazards related to the hydrogen use is very important in design. The design requirements are summarized in the Table 3.

Table 3
Design Requirements for Hanaro CNS

Item	Requirement
Gain factor	More than 20 for 5 Å
Cold neutron flux	More than 5 x 10^8 n/cm^2·sec at the end of cold neutron guide tube
Life time consideration	30 years
Applications	• Crystallographic studies • Neutron non-destructive evaluation • Small angle neutron scattering • Neutron reflectometry • Neutron inelastic for chemical analysis • Neutron and nuclear physics
Safety consideration	• Explosion due to hydrogen-air contact • The effect on reactor by installation of CNS(Reactivity, Pressure etc.)
Installation consideration	• To be installed in the existing vertical hole(φ 16 cm) • Minimize interfaces with the existing facilities in the reactor pool • Space limit for installation near reactor pool
Other	• Design of very-cold/ultra-cold neutron facility

3. MAIN CONCEPT OF THE CONCEPTUAL DESIGN

One of the main concepts is to use hydrogen-deuterium mixture which is more effective than pure hydrogen or pure deuterium for the small size sources. It was proved by the experiments performed at WWR-M reactor at PNPI.

One of the main problems of CNS installations at Hanaro is the presence of light water in the CNS hole. It lies in that even 1~2 mm water layer weakens cold neutrons considerably and thus gain of cold neutrons becomes not meaningful. It was proposed to dislodge water from the hole by filling helium gas in it. However this is complicated because of the irregular configuration of the hole and by impossibility of sealing in the upper part of the CNS hole. It seems reasonable to put a thin zirconium insert into the hole with a flange. This insert flange allows to realize the possibility of metal spring sealing. Installation of the insert allows to solve the problem of removing water by pressure of helium to be filled between the insert and containment.

The solution of the source safety problem depends on employment of the additional shell around the source containment. This provides a few advantages as follows ;

1) The source is isolated from water in reactor pool. Leakage will be instantly detected because helium cannot be frozen out at the temperature 20 K.
2) The gas shell prevents the penetration of impact wave in water in case of hypothetical explosion of hydrogen-oxygen mixtures.

Circulation of liquid hydrogen-deuterium mixture in thermosiphon loop helps to remove heat from the source. This method which is being used at WWR-M reactor successfully, in contrast with vapor-liquid-vapor circulation, is more effective.

The neutron guide system includes both neutron guides for cold neutrons and very cold/ultracold neutrons(VCN and UCN). The guide for polarized neutrons as well as splitting of cold neutron beams with the help of supermirror multislit bended assemblies is employed, which is rather original concept. Movable polarizer design is envisaged to allow occasionally to use non-polarized beam of high intensity. The polarized beam of neutrons with large cross-section(6x15 cm^2), that is, with maximum possible intensity is proposed to use in studies of fundamental physics, for example, in precise studies of neutron β-decay with a view to searching for possible deviations from standard model of weak interaction.

A distinctive feature is the extension of the scope of utilized neutrons up to 50~100 Å for VCN and 500~1000 Å for UCN. VCN-SANS using these very cold neutrons is proposed to study large-scale inhomogenety in substance. In addition, due to low initial energy of VCN($E< 5x10^{-5}$ eV), study of solid state dynamics becomes possible by means of upscattering process[1,2].

4. HEAT LOAD CALCULATION

The heat release in CNS includes heating due to neutrons(slowing down and absorption) and prompt γ-rays and β-radiation because of capture of thermal neutrons. Heating of construction materials such as Zr, Al, Cu etc. is a result mainly from the photon transport through these materials. Some heating occurs at the expense of β-particles. Neutron and gamma fluxes, spectra , neutron and gamma heating in CNS at 30 MW thermal Hanaro reactor power were calculated for different materials, which could be used as construction materials in CNS. The calculations were performed by the Los Alamos Monte Carlo code MCNP-3B[3], which is written on Fortran-77[2].

The calculation scheme is analogous to those used for the criticality estimation of the CNS channel. The 18 element fuel rods assemblies are loaded into all channels OR3~6 because the energy release becomes maximum in this case. For comparison calculations with unloaded fuel rods assembly from OR channels were performed, too. Instead, OR5 channel was filled by heavy water. The 3.5 ℓ liquid hydrogen CNS volume is placed into thin zirconium channel(0.5 cm thickness). Above and below CNS are vacuum.

The estimation for total heat load is shown in Table 4.

Table 4.
Total heat load

Items	Calculation	Value(W)
Source cell	380 gm x 0.48 W/gm	183
Delivery and outlet pipe lines	430 gm x 0.48 W/gm	207
Cooling neutron guide	210 gm x 0.45 W/gm	95
Liquid mixture deuterium and hydrogen in MC	2960 cm^3 x (1.35x0.2+0.64x0.8) W/gm x (0.07x0.2+0.165x0.8) gm/cm^3	340
Liquid mixture deuterium and hydrogen in tube	989 cm^3 x (1.35x0.2+0.64x0.8) W/gm x (0.07x0.2+0.165x0.8) gm/cm^3	113
Thermal conduction + black body radiation	10 % from total value	70

Heat load	without cooling neutron guide	915
Total heat load		1010

5. CALCULATION OF GAIN FACTOR

The calculation of local neutron fluxes, their spectra and gain-factors of CNS was conducted according to Monte-Carlo method with the help of OMEGA program. This program[4,5] is designed for calculation of criticality of reactor, neutron fluxes and reaction rates in 3-dimensional geometry. The program was initially coded in ALGOL. Subsequently, it was re-coded in FORTRAN-77[5] and modified for calculation of neutron fluxes in CNS filled with the mixture of para/ortho-hydrogen and ortho-deuterium at temperatures of 15~ 23 K.

Neutron scattering cross-sections in the CNS were calculated according to Young-Kopel's model[6] for molecules of ortho-deuterium, para-hydrogen and ortho-hydrogen at the temperature of 19K. Comparison of the calculated energy dependence of total cross sections for thermal neutrons for ortho-hydrogen, para-hydrogen and ortho-deuterium with the experimental values of cross section demonstrate a correctness of calculation model as in Figures 1 and 2. This unit is designed for calculations of 3-dimensional assemblies formed by nesting of cylinders, hexagons and right-angled prisms. Active core of the Hanaro reactor contains 36 fuel assemblies. CNS is represented as a rectangle prism with the cross-section equal to that of cylindrical CNS of the HANARO reactor. CNS was located in the D_2O reflector in the point of crossing the cylindrical vertical and rectangle tangential CN channels. The cross section of the CN channel was chosen 6 x 15 cm^2. In computations of the thermal neutron gain the thickness of the CNS was varied from 2 cm to 15 cm.

The main parameter to be calculated is a relative gain factor of a thermal neutron flux in the channel CN. The relative gain factor is calculated as the ratio of the gain factor for CNS filled with the mixture of moderator(ortho-D_2 , para-H_2 or ortho-H_2) to the gain factor of the thermal neutron flux in CN channel when CNS is empty and neutrons are thermalized in D_2O reflector.

Since it is not known what moderator will be in the CNS, it is needed to perform an optimization of CNS. The purpose of optimization is to obtain a maximal value of relative gain factor for the CNS with low volume and consequently low energy released in CNS. Calculation was conducted for several mixtures, and shows that the maximum value of relative gain factor is obtained for the mixture of ortho-D_2 and para-H_2 with the

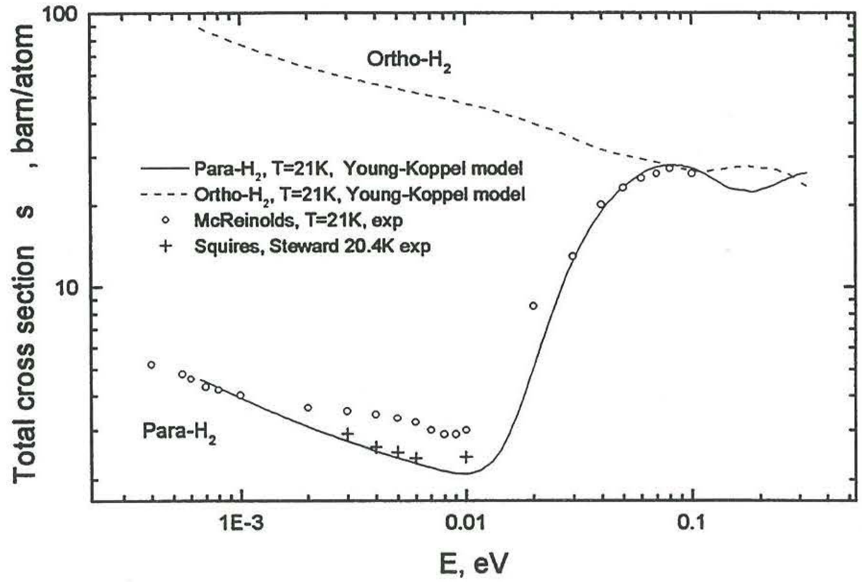

Figure 1
Comparison of cross-sections using Young-Koppel's scattering model with measurements of cross sections in liquid ortho/para-H_2 at 19K.

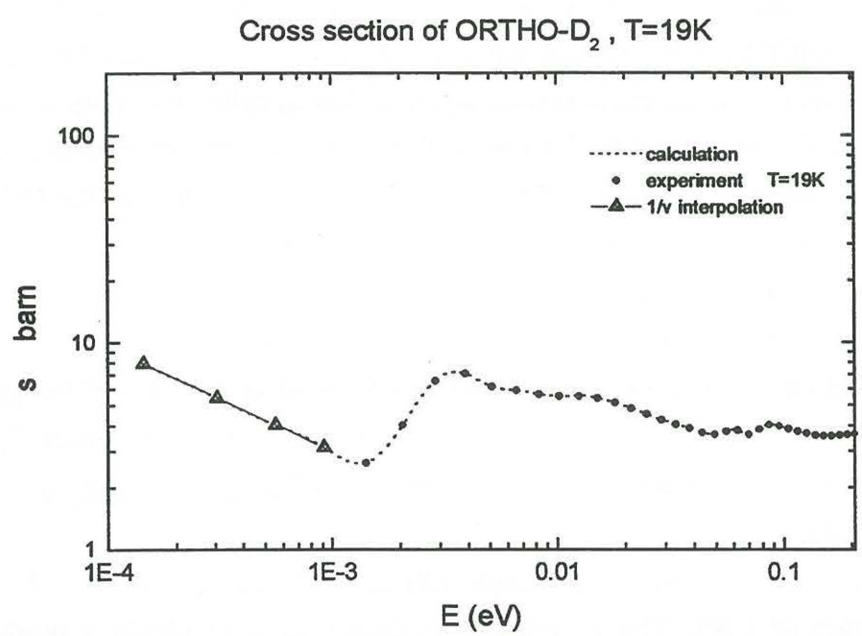

Figure 2
Comparison of cross-sections using Young-Koppel's scattering model with measurements of cross sections in liquid ortho-D_2 at19K.

ratio 0.8 : 0.2 as in Figure 3 and 4. For pure hydrogen moderator, several thickness for same mixing ratios of para and ortho H_2 were considered to find optimum thickness. Figure 5 and 6 shows the result that 3~4 cm thickness represents the maximum gain value for 50 : 50 % mixing ratio of para and ortho H_2.

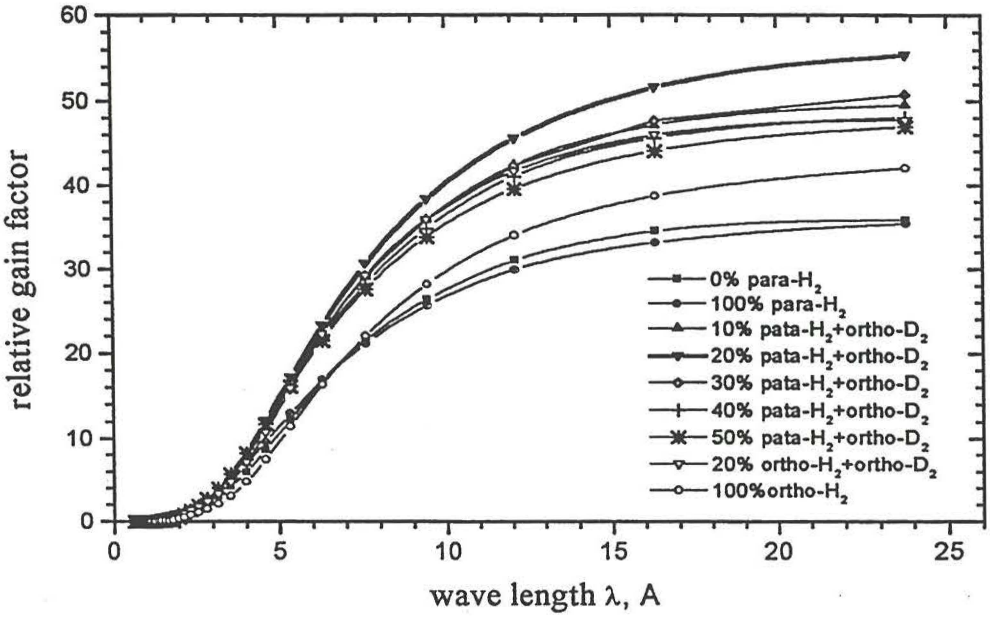

Figure 3
Relative gain factors for mixtures of ortho-D_2 with para-H_2 and ortho-H_2.

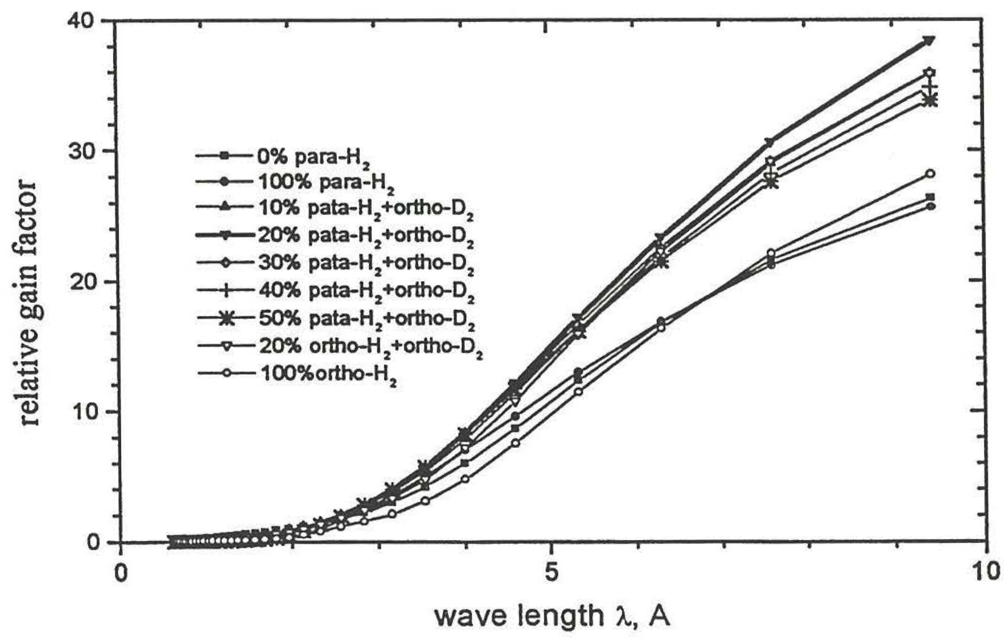

Figure 4
Relative gain factors for mixtures of ortho-D_2 with para-H_2 or ortho-H_2 (for wave length ~4-10 A)

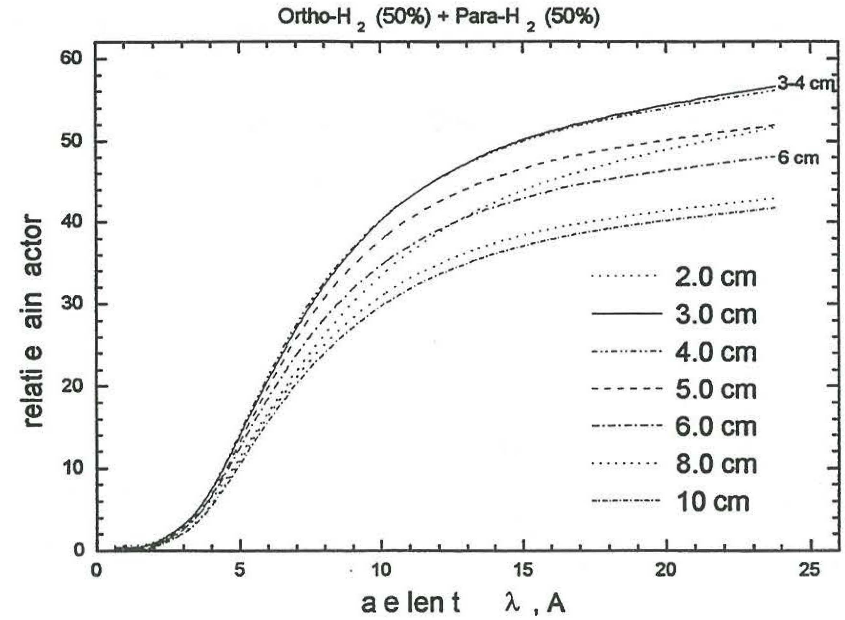

Figure 5

Relative Gain factor for para-ortho H_2 mixture

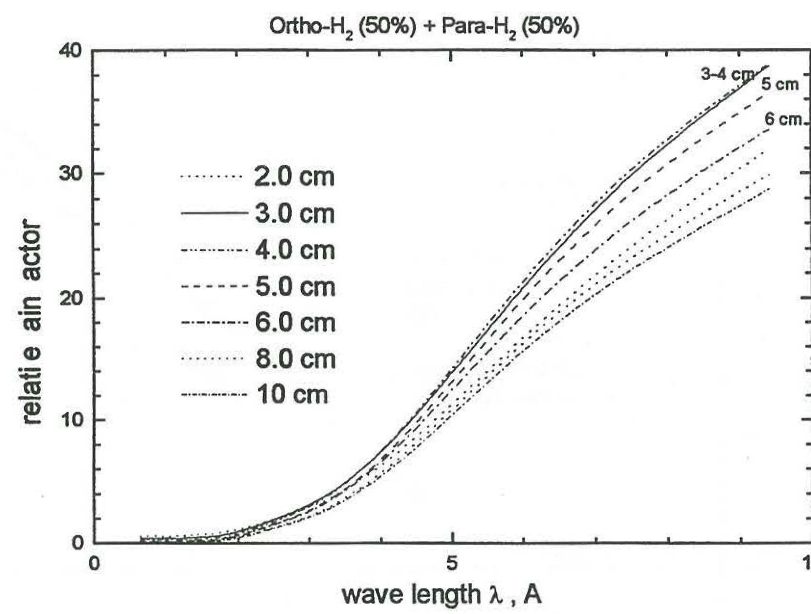

Figure 6

Relative Gain factor for para-ortho H_2 mixture

(for wave length 3~10 Å).

6. CNS EQUIPMENTS AND ARRANGEMENT

Horizontal neutron beam tube for cold neutron extraction is attached by weld to this reactor hole. There is a thimble with hole flange above the chimney base plate for CNS assembly installation. A special insert is placed into the reactor hole to exclude water gap between the cold neutron beam tube and the source cell and to correct curvature of the hole. The insert has a flange at the upper part and looks like thin tube. There is no gap between insert and reactor hole in place where the CN beam tube is situated. CNS containment is installed into the insert. There is a helium input to the top of insert to dislodge water in the gap between containment and insert. CNS arrangement in the reactor hole is shown in Figure 7.

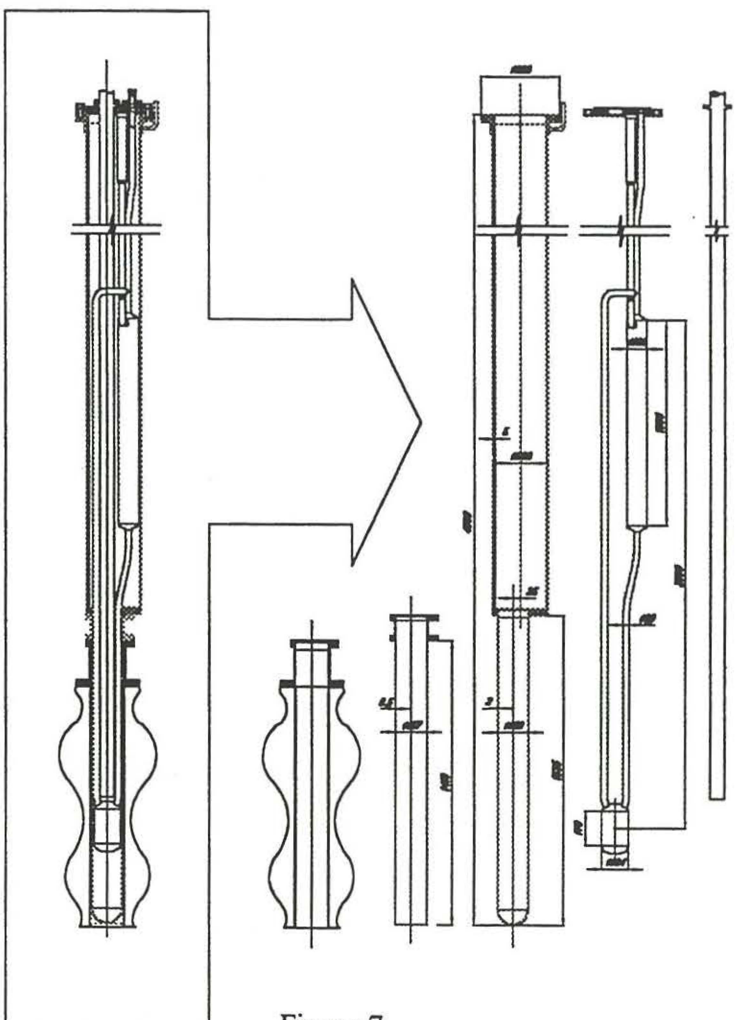

Figure 7

In-Pile CNS Arrangement

The vertical containment has a cylindrical shape and consists of two parts with different diameters. The lower part has a spherical bottom. The containment is supported by insert flange due to its own plate flange between parts with different diameters. The upper part of containment is surrounded by shell with helium and has a ring flange. This flange is 0.3 m above the level of chimney top.

There are thermosiphon liquid moderator loop and neutron guide for VCN and UCN inside the containment. The liquid moderator loop consists of cell, heat exchanger and connecting tubes. Moderator cell has volume about 3 ℓ and places in front of CN beam tube. The cell is made of Al. or Zr. The average temperature in the cell is about 19 K and the working pressure is about 1.5 bar.

Single phase thermosiphon is used to have an advanced liquid moderator source. The moderator is maintained at few degrees below the boiling point. The loop height is only 2.5 m so that it is placed entirely in a vacuum containment and placed in the reactor pool. The tube diameter is 30 mm. The capacity is up to 1500 W with cold helium flow rate 50 g/s. The thermosiphon loop is shown in Figure 8.

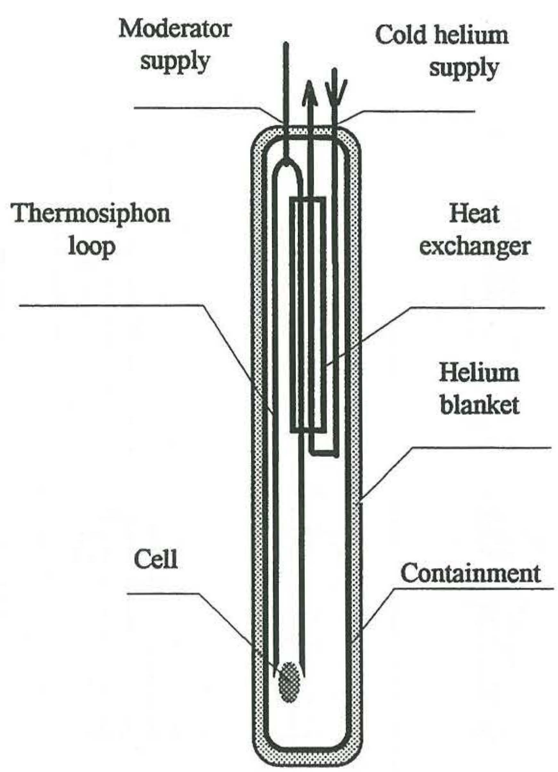

Figure 8.
The liquid thermosiphon loop

VCN and UCN come out from the source through the vertical curved neutron guide with cross section 7x10 cm in the reactor pool as shown in Figure 9 and 10. There is a split section for VCN and UCN separation out of the reactor pool. After separation VCN can be used for scattering experiment, UCN can be used for storage experiment. There are two platforms for experiments with VCN and UCN one above another.

7. NEUTRON GUIDE SYSTEM AND INSTRUMENTS

The task of the neutron guide system is to transport neutrons produced in the cold neutron source to experimental devices which is intended to perform scientific investigations with neutrons. Transportation of neutrons is realized on the base of the mirror reflection of cold neutrons from the walls of the neutron guide. The curved neutron guide channels can be used to cut off fast neutrons and gamma radiation because their total reflection coefficients are negligible in comparison with that of cold neutrons. The neutron guides are channels with rectangular cross section, prepared by using mirrors with a glass substrate and ^{58}Ni reflecting coating. The internal cross section is of 40 mm width and 140 mm height.

There are three main neutron guides. The neutron guide system is adapted for installation of 10 scientific instruments as in Figure 11. Configuration of outlet hole makes it possible to install 3 neutron guides with cross-section 30 x 150 mm. The first neutron guide(NG-3) with characteristic wave length $\lambda^{*}= 2$ Å is made on the basis of polarizing supermirrors. So the instruments installed on this neutron guide use a prepared polarized neutron beam, which makes it unnecessary to install polarizers on each instrument and simplifies the instrument design. The neutron guide accommodates 3-axis spectrometer(TASPN), spin-echo spectrometer(NSES), and the instrument with 3-dimension analysis(TDA) of polarization for study of magnetic texture and other 2 instruments. The 2nd guide(NG-2) installs only one instrument of great length-small angle polarized neutron(SAPNS)- with its own polarizer and magnetic monochromator. Monochromator on the basis of space spin-resonance is better than mechanical velocity selector because it allows to change the wave length and width of monochromatic line by simple alteration of magnetic field. The 3rd guide is equipped with DPCD, PNRV, CS and SANS. This has 3 branches of non-polarizing neutron guide with characteristic wave length $\lambda^{*}= 2$, 3 and 6 Å. At the first part, double crystal diffractometer with perfect crystals(DPCD) is installed.

The main instrument is SANS with high intensity and resolution for transferred momentum at the level 10^{-2} $Å^{-1}$. One of the branches with wave length $\lambda^* = 6$ Å leads to reflectometer of polarized neutrons(PNRV) with reflection in vertical plane and TOF analysis of neutron spectrum, and another with wave length $\lambda^* = 3$ Å leads to correlation spectrometer(CS) with pseudorandom modulation of polarization and TOF correlation analysis[7, 8, 9]. Total area of the neutron guide will be 36x 60 m^2.

8. CONCLUSION

Cold neutrons has been used extensively for the study of the structure and dynamics of materials in some advanced countries during the last decades or so. The cold neutron source at HANARO will be designed from the end of 1996 and the installation will be completed by the end of 2001. The cold neutron experimental instruments at HANARO will be utilized for studies in the broad category such as crystallography, magnetism and superconductivity and surface and interfacial studies etc. With the completion of the CNS facility, the study of the material science, solid physics, chemistry and biology etc. will be going on more vigorously centering around the HANARO.

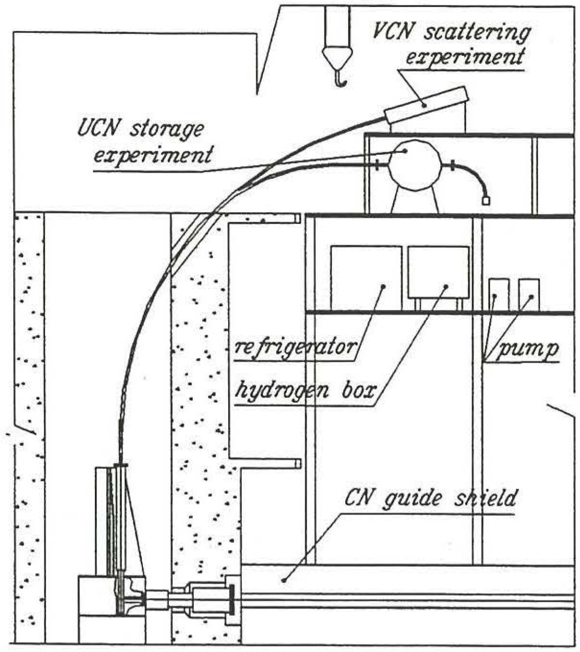

Figure 9.
CNS equipment arrangement in CN guide direction

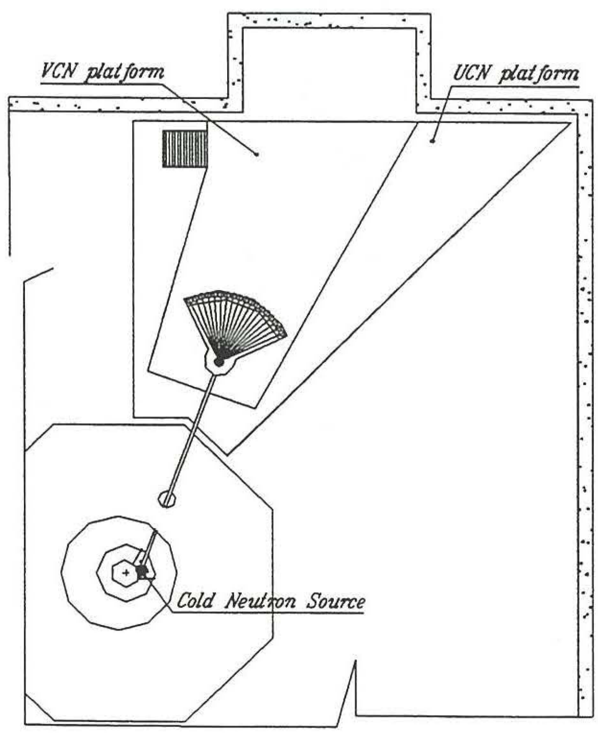

Figure 10.
CNS equipment arrangement (top view)

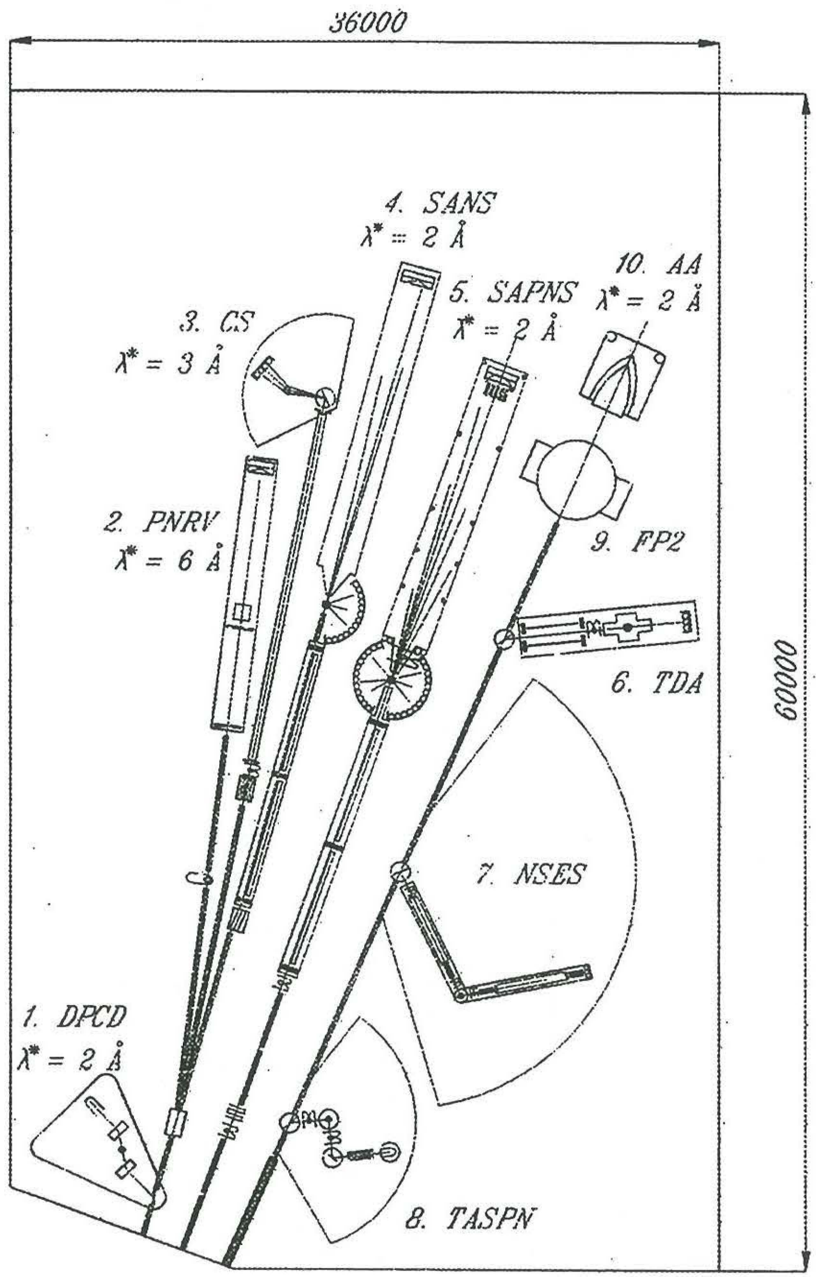

Figure 11.
Instruments in the neutron guide hall

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