Proceedings of the Korean Nuclear Society Spring Meeting
Kori, Korea, May 2000

1st Period Research of the Concept Design of a HANARO Cold Neutron Source

Cheul-Muu Sim, Kook-Nam Park, Young-Hyun Choi, Jae-Min Sohn
Man-Soon Cho, Chang-Hee Lee, Chang-Oong Choi

Korea Atomic Energy Research Institute

Abstract

HANARO construction has been successfully completed, which is a pool type of 30 MW thermal power and achieved its first criticality in February, 1995. In order to activate advanced researches on neutron application, efforts for utilizing the facilities on the HANARO reactor have been made. KAERI has formed a department to suit the need for installations of a cold neutron source and the concept design work of CNS has begun. The major engineering targets of this CNS facility are established for a minimum physical interference with the present facilities of HANARO, a reach of very high gain factors in the cold neutron flux, simplicity of the maintenance of the facility, and safety in the operation of the facility, as well as the reactor. For the conceptual design of the HANARO CNS, the experience of utilization and production of cold neutron at PNPI, ORNL, JRR-3M, Technicatome and so on has been used. Requirements were developed for the completion of each phase. After the concept design, the action plans are listed for the detailed design, fabrication, testing and installation

I. Introduction

The purpose of the cold source is to increase the available neutron flux delivered to the instruments at wavelength 4 ~ 12 Å. The major engineering targets of this CNS facility are established for a reach of very high gain factors in the cold neutron flux in consideration with the moderator, the circulation loop, the heat load, simplicity of facility maintenance, safe operation of the facility against a hydrogen explosion and the layout of minimum physical interference with the present facilities. The CNS of HANARO was originally designed and shaped to accommodate the Orphee-type CNS concept that is a vertically shaped 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

HANARO. Therefore, some special concept of the CNS must be developed for protecting the reactor core from an explosion of H_2O_2 in the case that the condenser or heat exchanger may be installed near the core in the reactor pool. At the beginning of the concept design of the CNS, the Orphee type or JRR-3M type CNS were intensively reviewed for the adaptation into HANARO, and in consequence, significant physical modifications are necessary to accommodate them into HANARO, implying that it is imperative to develop the requirements to resolve the very serious licensing problem. [1,2]

II. Concept design of CNS

The cold source project has been divided into 5 phases: (1) pre-conceptual (2) conceptual design (3) Testing, (4) detailed design and procurement (5) installation and operation. Although there is sometimes an overlap between the phases, in general, they are sequential. The pre-conceptual design and concept design of KCNS has been performed on elaborations of PNPI Russia and reviewed by Technicatome, Air Liquid and Cilas France. In the design of a cold neutron source, the characteristics of the cold moderators have been studied to obtain the maximum gain of cold neutrons, and the analysis for radiation heat, design of the hydrogen system, vacuum system and helium system have been performed. The possibility for materialization of the concept in the proposed conceptual design has been reviewed in view of securing safety and installation at HANARO. Above all, the thermosyphon system to remove heat by the circulation of sub-cooled liquid hydrogen has been selected so that the whole device could be installed in the reactor pool with a reduced volume. Hydrogen safety has been considered to preclude the formation of a hydrogen-oxygen mixture and to prohibit a hydrogen-oxygen reaction.

2-1.Phyiscal analysis for design philosophy[3,4,5]

The cold source shall be designed assuming reactor operation at 30 MW. In consideration of the thermosyphon, a vertical hole has been installed in HANARO. The thermosyphon is even safer than the supercritical hydrogen system due to the simplicity of sealing and the non-existence of a flammable source of circulator power. One of the main problems of CNS installation at HANARO is the presence of light water in the CNS hole. This lies in that even a 1-2 mm water layer weakens the cold neutrons considerably and thus the gain of cold neutrons become un meaningful. Before a vacuum chamber and moderator cell for the cold neutron source are installed, it is necessary to measure the exact size of the inside diameter and thickness of the CN hole of fig. 1, which might have experienced in corrosion and deformation, for a good fitting. Due to inaccessibility and high radiation in the CN hole, a mechanical method is not permitted. The immersion ultrasonic technique of 2 is allowed to be the best method for a precision measurement of the thickness and diameter. The 4 axes manipulator of the 2 channels of the sensor module is assembled. The transducer, 10 MHz, permits a 0.01 mm resolution tolerance. The data is obtained by measuring 550 point of the hole. The result shows that the thickness is in the range of 3.3-6.7 mm as shown in fig.3 and the inside diameter is in the range ϕ 156-165 in fig 4. The basic data of measurement of CN hole is referenced not only in the design of a neutron source facility but also in a routine inspection according to IAEA ID 35-G7.

For heat load determination in the CNS hole of the HANARO reactor, the activation method of measurement of the thermal, epithermal and fast neutron fluxes, the I-C gray method of measurement of the heating rate of g in fig and the Monte-Carlo method of calculation are carried out. The measurement results of the neutron fluxes for the experiment are in good agreement with the CNS model of MCNP as shown fig.5. Analysis of the heat release data from g -rays has shown that the measurement results are greater than the CNS model of MCNP which does not include the effect of delayed gamma ray and light water as shown in fig.6. It is necessary to adopt the calibration method for reliability.

In preparation of the concept design, a mono-phase moderator is recommended by PNPI. At this pressure condition, the temperature gap between the boiling point, 13.9K, and the solidification point, 18.9K, was very narrow and will require very precise temperature monitoring. Therefore, the two-phase was suggested by Air Liquid during the review. An experimental study of fig. 7 was carried out to delineate the flow characteristics in a closed counter-current two-phase thermosiphon with concentric tubes. In the present investigation, experiments with Freon-113 as a moderator were performed. The results show that, based on the magnitude of the pressure fluctuation, the flow regions could be divided into 4 distinct groups in the ($V_{f,}$ Q_i) plane of fig.8, where $V_{f,}$ represents the volume of the charged liquid and Q_i is the heat load: stable flow region, an oscillatory flow region, a restablized flow region and a dry-out flow region. For $V_{f,}$ > 2.5 liters, the flow is stable at low. However, as Q_i increases, the flow becomes oscillatory and finally restablizes. As $V_{f,}$ increases, the oscillation amplitude decreases, reaching to the restablized flow region at low Q_i and the liquid level in the moderator cell remains high. In the oscillatory flow regions, for a fixed region, the oscillating period of time varies with Q_i, having a minimum value at a certain value of Q_i. The heat load, where the oscillating period of time is minimum, decreases as $V_{f,}$ increases. The results of the thermosyphon test using Freon-113 for stability should be referenced for a moderator. 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 a CNS filled with the moderator of liquid hydrogen to the gain factor of the thermal neutron flux in the CN channel. In a pure hydrogen moderator, several thickness for the same mixing ratios of para and ortho hydrogen were considered to find the optimum thickness. Fig 9 shows the result that 3~4 thickness represents the maximum gain value for a 75:25% mixing ratio of para and ortho liquid hydrogen is the most appropriate moderator for the reach out gain factor. The integrity test of a hydrogen explosion will be carried out to measure the velocity, pressure, stress, strain, displacement and flaw detection for a detailed design during the 2nd period of research for the concept design as shown in fig.10

2-2 CNS equipments and lay-out

A horizontal neutron beam tube for cold neutron extraction is attached by a weld to this reactor hole. There is a thimble with a hole flange above the chimney base plate for CNS assembly installation. A special insert is placed into the reactor hole to exclude the 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 the 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 the insert to dislodge water in the gap between the containment and the insert. The CNS arrangement in the reactor hole is shown in fig 11. The general arrangement of the CNS facilities are based on the data of the existing facilities of other countries such as JRR-3M. Orphee has been investigated and the interferences with the currently operating reactor have been reviewed, which will be used as the data of the basic design. The concept of the facility layouts reflect the principles of convenient operation, safe operation and economic design. As a result, 4 guides will be installed into the neutron guide hall which has a size of 36m x 60 m x 15 m(H) and contain more than 10 spectrometers. 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 a rectangular cross section, prepared by using mirrors with a glass substrate and ^{58}Ni reflection coating. The internal cross section is 40mm in width and 140 mm in height.

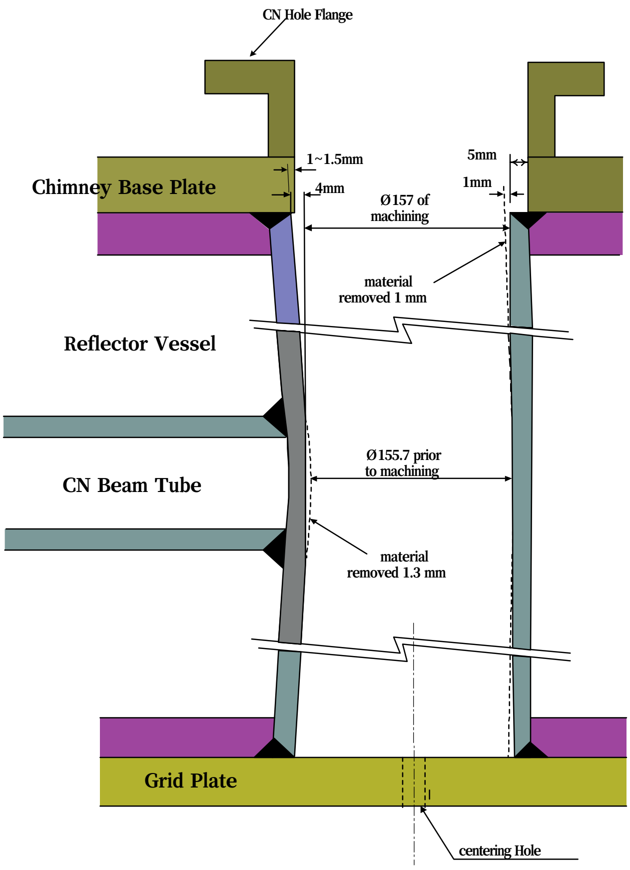


Fig.1 Sketch of the CNS hole in HANARO

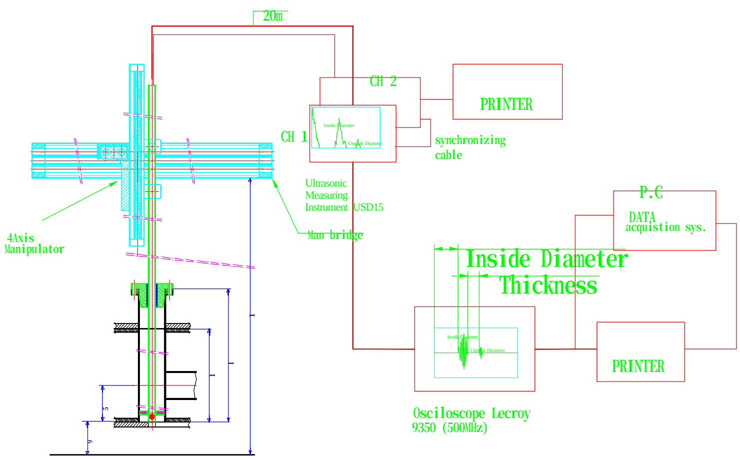


Fig.2 Diagram of Ultrasonic measurement

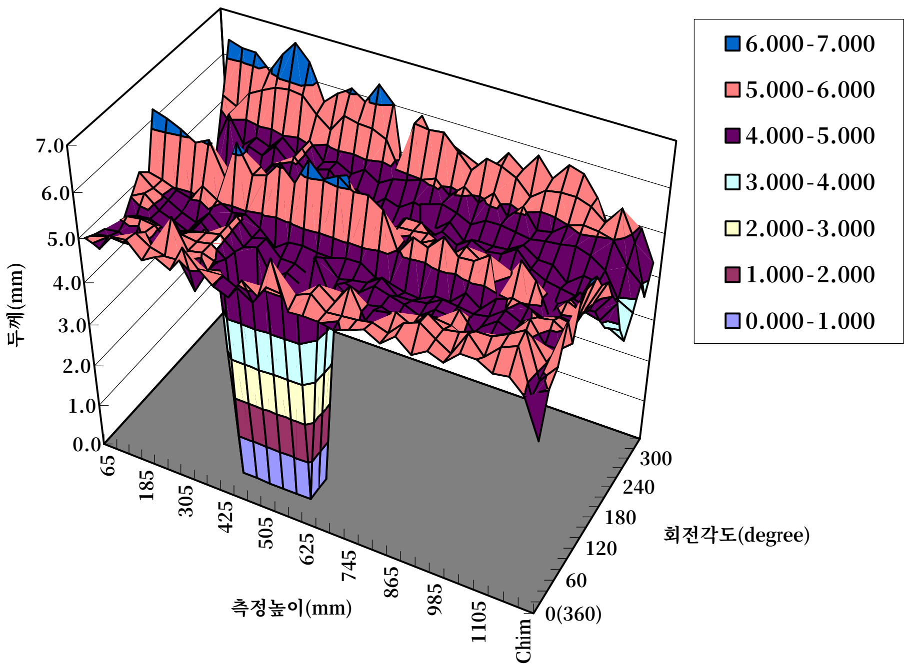


Fig.3. 3D image of CN hole thickness

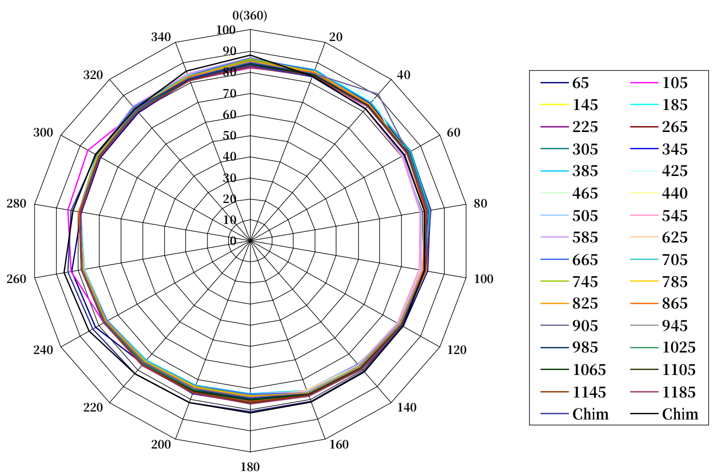


Fig.4 2D image of CN hole Diameter

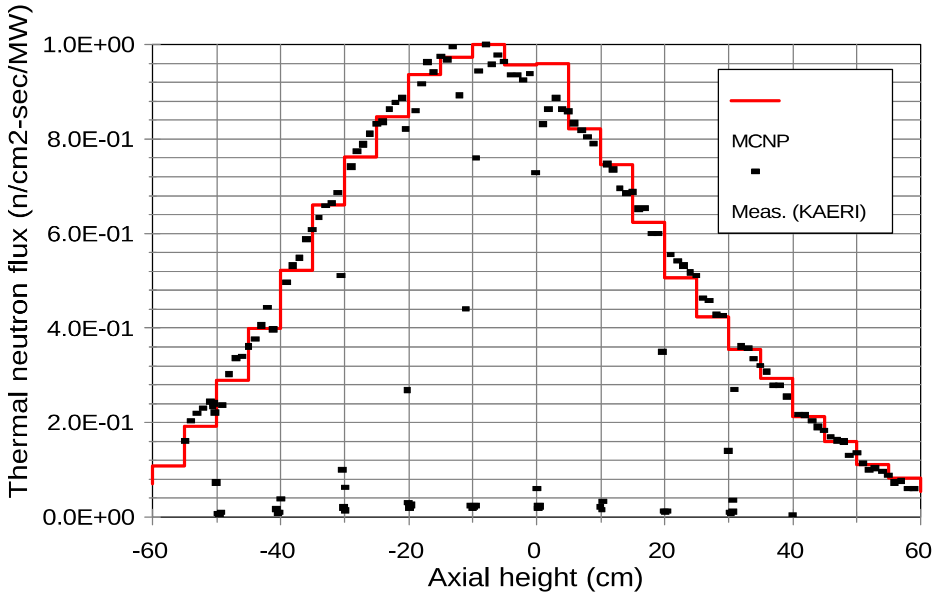


Fig.5. Heat Load of thermal Neutrons

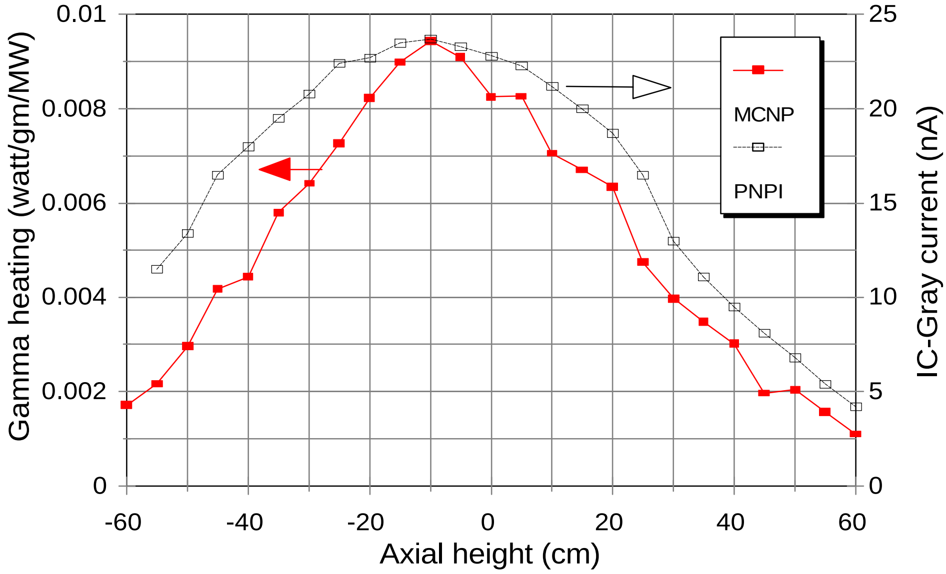
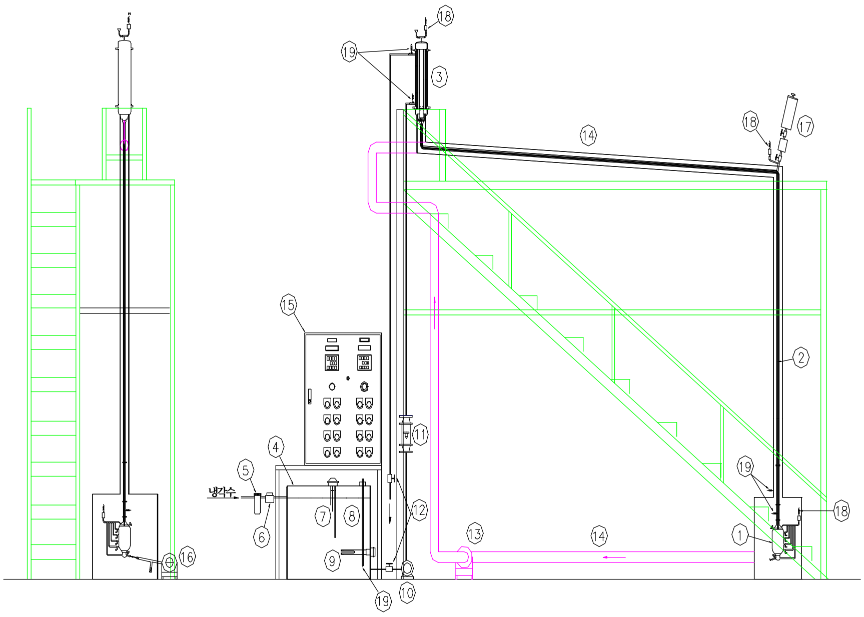


Fig.6. Heat Load of *g* heating



품번	품 명	품번	품 명	품번	품 명	품번	품 명	품번	품 명	품번	품 명	품번	품 명
01	감속재용기	04	항온조	07	Level sensor	09	5kW 히터	12	유량조절밸브	15	제어판넬	18	압력계
02	열사이펀관(내.외관)	05	필터	08	항온조제어용	10	냉각수순환 펌프	13	Dryer heater	16	진공펌프	19	T/C
03	응축기	06	Solenoid valve		T/C 지지봉	11	유량계	14	Hood	17	Freon 주입기		

Fig.7 Experiment for thermosyphon using Freon-113

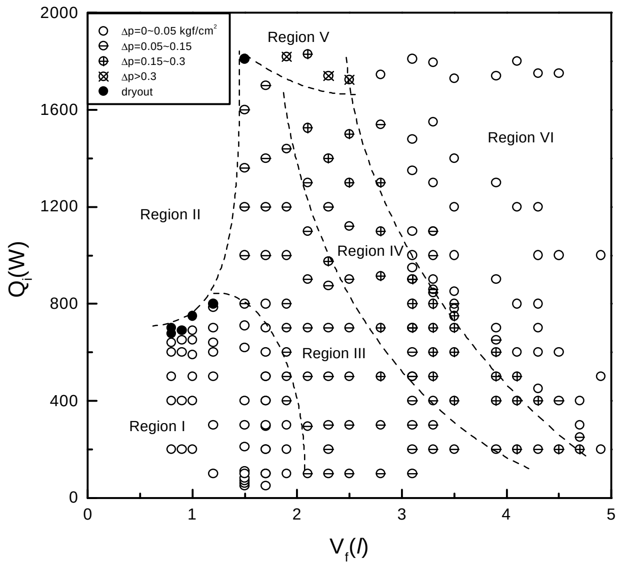


Fig.8. V_f, Q_i diagram of flow characteristic

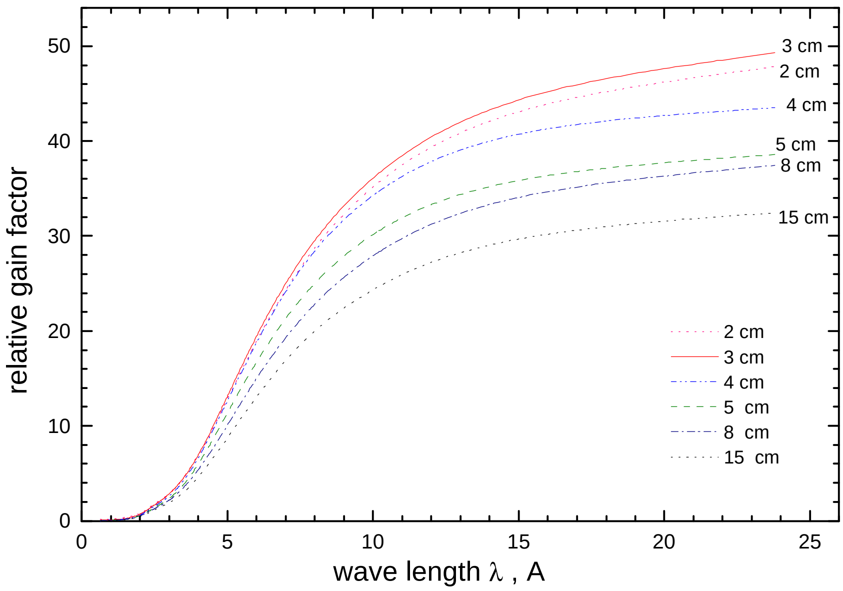


Figure 9. Ortho-H_2 (75%) and para-H_2 (25%) gain factor(T=19 K).

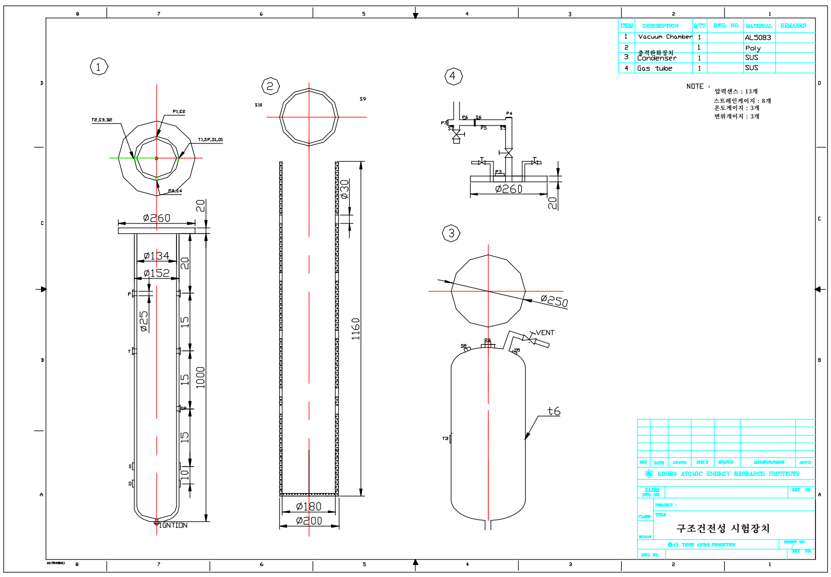


Fig. 10 Explosion test for CNS facility integrity

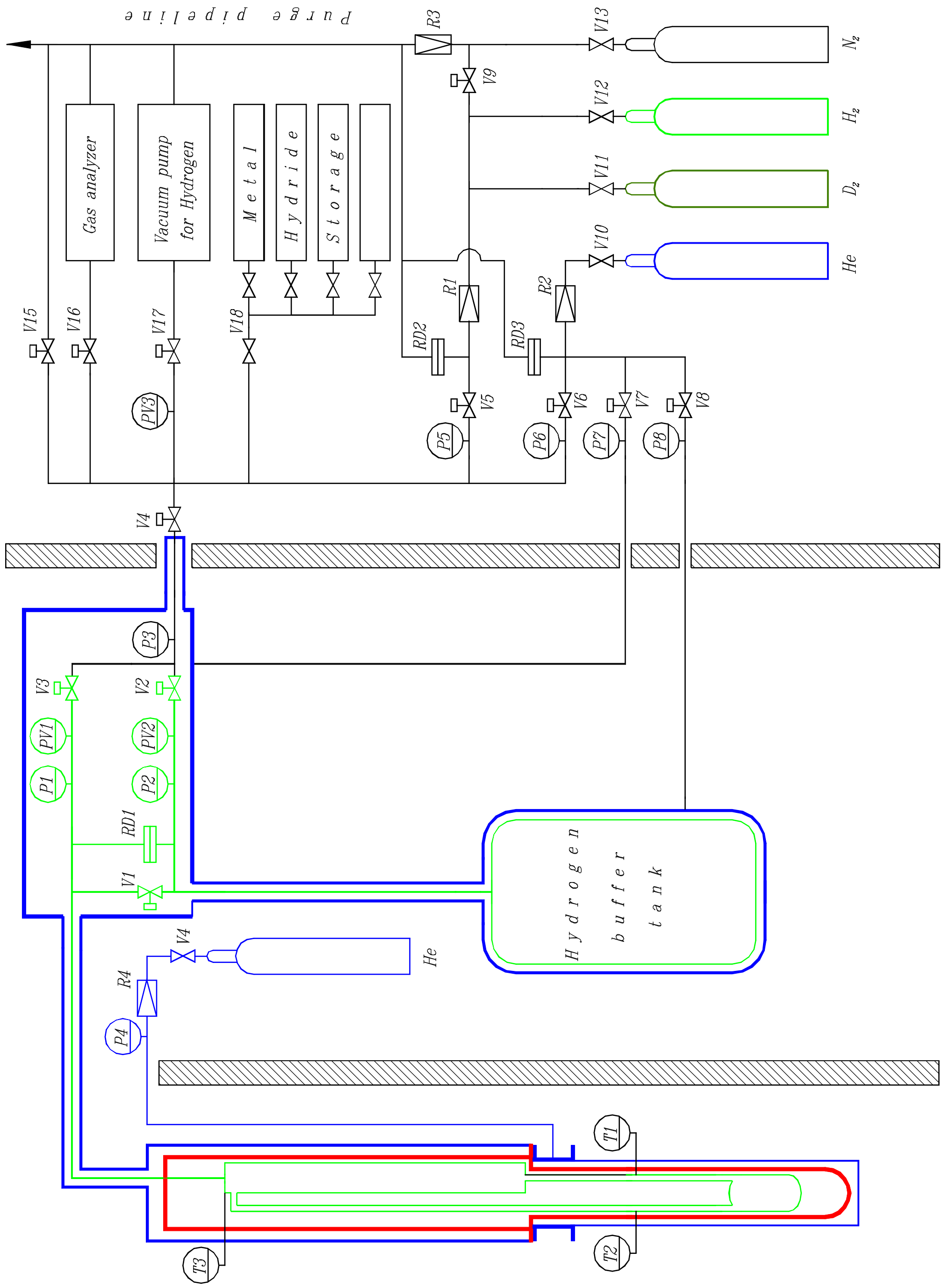


Fig.11 Hydrogen loop of in pile assembly

III. Requirements[6,7]

3-1. User requirements.

The purpose of the cold source is to increase the available neutron flux delivered to the instruments at wavelength 4 ~ 12 Å. The gain factor on the brightness for these wavelength should be comparable to an existing similar cold source.

3-2. Regulatory compliance requirements

The installation of the cold source cryostat shall be performed per the procedures written to the requirements procedures. The technical safety requirement modifications needed to support the operation of a cold source shall be approved and issued prior to installation. The requirements of environmental protection shall be completed prior to the detailed design of the cold source. SAR and PRA shall be revised to reflect an inclusion of the cold source at the PRA update following the installation of the cold source.

3-3. Safety requirements

The cold neutron source facility will be designed such that there is a low probability of $10^{-6} / year$ and the dealing of hydrogen shall follow the guidance of the National Aeronautics and Space Administration (NASA). The vessel and piping that comprise the primary hydrogen barrier shall be designed and fabricated according to the ASME Boiler and Pressure Vessel Code Sec III. Code Case N-519-Use of 6061-T6, 6061-T651, ASME B31.3, Chemical and Petroleum Plant Piping. The vacuum tube shall be designed to withstand the external pressure produced by a leaking beam tube. During the hydro-test, special measures shall be taken to ensure the integrity of the vacuum tube. The consequence of events that involve beam tube failure shall be analyzed and shown to be less than the SAR acceptance criteria. For the limiting events, which include a low probability sequence in the frequency range of 10^{-4}-10^{-6}/year, the sequence must be lower than the 10 CFR 100 off-site dose limit. For beam tube failure initiated events, the proposed modifications to the beam tube, ORNL/TM-5711/R2 TS3.8.3(b)(2), limit the consequence to a SBLOCA(small break loss of coolant accident) to no more than 100 gpm at 690 psig.

3-4. Operation requirements

The procedures and requirements of the configuration control of the plant design modification shall be provided for design. The procedure “Procurement of items and services” shall be issued for the procurement requirements and fabrication requirements. Radiological conditions in the beam room and experiment room should be maintained at a current level. The cold source should be designed to minimize the administrative reactor shutdowns to protect the cold source equipment. The design of a cold source control and automated safety systems should be such as to eliminate the need for a dedicated cold source staff s during off-shifts.

3-5. Maintenance Requirements

Installation of all ex-core cold source components shall be administered through the procedure “Preparing and Processing a Maintenance work package”. A break down of the maintenance procedures shall be developed, approved and issued prior to initial reactor operation with the cold source cryostat installed. A preventive/reliability centered maintenance program for cold source equipment should be developed and implemented prior to initial operation.

IV. Future scope and conclusion

The results of every phase should be fully transferred to the consecutive phase via the RAM(reliability, availability, maintainability) program and Risk program. In 2003, the 2nd research of a cold neutron source project plan will be resumed. These results will be reflected on the analysis and plan which are as below.

1. Accident analysis

Accident analysis will be carried out on the basis of JRR3 and Orphee type. Accident analysis is categorized as follows.

- loss of adequate ability to remove heat from the moderator vessel walls
- loss of liquid hydrogen flow
- loss of helium refrigeration
- loss of vacuum
- loss of tertiary containment
- hydrogen leaks/ transfer line breaks
- loss of off site power control system failure, and gas transport/ handling event
- heat removal from the thimble under steady state conditions
- stress analysis of thimble components
- analysis of liquid hydrogen vaporization and flow into the expansion vessel and the heat transfer analysis of the gas/liquid interface vessel

2. Construction and installation operation plan

3. Procurement plan

4. Quality assurance plan

5. R&D testing and evaluation plan

6. Start-up testing plan

7. Configuration management plan

8. Reliability/availability/ maintainability (RAM) plan

Cold neutrons have been used extensively for the study of the structure and dynamic of materials in some advanced countries during the last decade or so. The concept design phase of cold neutron at HANARO will be finished the end of 2nd period and installation will be completed by the end of the 3th period. The cold neutron experimental instruments at HANARO will be utilized for studies in the broad categories such as crystallography, magnetism and superconductivity and surface and interfacial studies etc. With the completion of the CNS facility, the study of material science, solid physics, chemistry and biology etc will be going on more vigorously centering around HANARO

----This work was supported by a long term research project of MOST--------

References

1. C.O. Choi, Development of cold Neutron Source, KAERI/RR-1916/98.
2. C. O. Choi, Development of the cold Neutron Source, KAERI/RR-1728/96
3. K.N. Park, Measurement of the shape by an ultrasonic wave and the surface inspection of a cold neutron source vertical hole, KAERI-TR-1261-99
4. J.M. Sohn, Measurement and analysis heat load in CN hole of HANARO, KAERI/TR-1276/99
5. M.S. Cho, et al, " An experiment for thermosyphon using Freon-113" pp 121,Proceeding of the Korean Nuclear Society Fall Meeting Seoul, Korea, Nov.1999
6. D.L. Selby, High Flux Isotope Reactor Cold Source Preconceptual Design Study Report, ORNL/TM-13136
7. D.L. Selby, High Flux Isotope Reactor Cold Neutron Source Design Concept, ORNL/TM-13136