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HANARO Cold Neutron Source Design

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1. Introduction

The cold neutron source (CNS) design has been completed and confirmed by the full scale mock-up test. When its licensing is expected to be issued within 2007, the CNS will be installed in HANARO in 2009 and be operated from 2010 after the commissioning. The production of cold neutrons from 2009 will enable the neutron guides and the scattering instruments to be commissioned in parallel. From 2010, a new era of neutron science will be open in the area of bio-technology, nano-technology, and material science through the probing capability of cold neutrons with nano-wavelength. The prominent research output that will be created from this cold neutron research facility will ensure the basic science and technology, which will provide the strong foundation for the advanced engineering and technology.

This paper presents the design of in-pool assembly including the nuclear design of moderator cell, the manufacturing test of in-pool assembly, the full scale mock-up test, and the safety analysis.

2. In-pool assembly design

The cold neutron source itself means the moderator which slows down the thermal neutrons by one or two collisions with 20 K of liquid hydrogen. Then the temperature of neutrons becomes 55 K in equilibrium and its energy of about 5 meV which is one order less than the thermal neutrons. Although the corresponding wavelength is 4 Å, quite number of neutrons with the wavelength of 12 Å is expected in the neutron distribution which is the upper bound of the wavelength that the neutron scientists are interested in. Of course, the liquid hydrogen is not the only kind of the moderator but it is the best solution when the size of the cold neutron hole in the HANARO reflector is already given as 160 mm.

Maintaining the liquid hydrogen safely in the reactor demands careful engineering. The material of moderator cell containing the liquid hydrogen should be proven in the radiation and the cryogenic environment. Al6061-T6 meets those requirements and already is being used in other CNS abroad. The thinner moderator cell thickness is the better for less nuclear heating and less neutron absorption. The shape design of the moderator cell is the main part of the CNS nuclear design to direct more cold neutrons to the neutron guide and eventually to the neutron scattering instruments.

What should be considered most in the moderator cell design is not how many neutrons that can be produced in the moderator volume but how many neutrons that can be seen in the neutron guide. It is why the neutron brightness is used instead of neutron flux as a main nuclear design parameter. The maximum thickness of liquid hydrogen is about 30 mm and not more than that to prevent more nuclear heating in the moderator. A cavity is placed in the moderator cell off centered to the neutron beam tube side to lessen the neutron up-scattering. Also considered is the fact that there will be hydrogen vapor in the moderator and the void fraction will be about 20 %, which is confirmed in the mock-up test later on. When the gain factor is defined as the ratio of cold neutrons with CNS to those without CNS, the HANARO CNS gives the maximum gain factor of 42 at 11.8 Å and the average one between 4 and 12 Å is 31.7.

The evaporated hydrogen from the moderator cell by the nuclear heating follows the transfer tube of a double cylinder type and the liquefied hydrogen in the heat exchanger flows down back to the moderator cell, which is called thermo-siphon. The moderator cell, the heat exchanger, and the piping are included in the vacuum chamber for thermal insulation, which is loaded in the CN hole of HANARO reflector tank in the reactor pool and is called in-pool assembly.

The structural analysis of the moderator cell has been performed by the design requirement of ASME Boiler and Pressure Vessel Code, Section III Sub-section NB, 1998 Edition, 2000 Addenda. The results are within the allowable stress defined in ASME. The structural integrity of the vacuum chamber, upper and installation flange, and the fixing support has been also verified.

3. IPA manufacturing test

The IPA has been manufactured as quality class of S and used in the full scale mock-up test. The moderator cell has been manufactured with the thickness of 1 mm and passed the dimension test, radiation NDT, leakage and pressure test, tensile test at room and cryogenic temperatures, and structural test at the welding part. The shell and tube type heat exchanger has been also manufactured and went through cryogenic vacuum test and fatigue test as well as the dimension test, welding test, and leakage test.

The vacuum chamber with the same weight as the real one but without the inner component has been manufactured. The installation test of IPA has been done several times with that, which made the design modification of adapter plate, bracket, and installation plate.

Figure 1. Cryogenic leak test of moderator cell at 77 K

4. Full scale mock-up test

The objectives of this mock-up test are the validation of the detail design of IPA and the establishment of normal and abnormal operation procedure. This test has been carried out with the working fluid of hydrogen, which was possible since the refrigerator with the proper capacity for this test was available. The test facility is shown in figure 1.

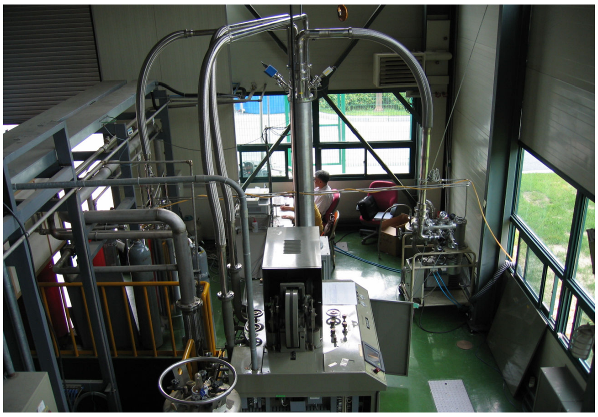

Figure 1. Full scale mock-up test facility

The design validation tests include vacuum test and heat penetration estimation. Through the thermo-siphon confirmation and void fraction measurement by gamma densitometer, the dynamics in the thermo-siphon could be investigated and the operation procedure be established. The malfunction of the refrigerator and the vacuum loss in the IPA have been simulated for the abnormal events. These tests provide the basis for the establishment of the reactor trip setpoint to protect the CNS.

Assuming the spacer material among some candidates does not affect much to the total heat penetration amount, both the analytical evaluation and the measurement are lower than the design value. The heat load measurement in the HANARO is also lower than the design value. These facts confirm that the design values of heat loads and heat penetration is conservative when they are used for the determination of the capacity of refrigerator.

5. Safety analysis

The vacuum chamber design that can withstand the maximum pressure in the postulated event of hydrogen-oxygen chemical reaction is the key issue in the safety analysis. Based on the experiments and the analytic calculation with sufficient safety margin, the design pressure of the vacuum chamber has been evaluated and its thickness was obtained by the structural analysis against this postulated event. The accident scenarios have been analyzed with the initiating events such as hydrogen-oxygen chemical reaction, refrigerator malfunction, and fire. In any events, it has been concluded that HANARO maintains its integrity.

6. Conclusions

The safety analysis report has been submitted to the regulatory body and it is expected that the construction and installation permit will be issued within a few months. With two years left before the cold neutron production, the interface with the related engineering systems and the reactor should be carefully engaged and the commissioning and operation procedures should be prepared in advance.

This cold neutron research facility will be the last one that is installed in the HANARO and then the utilization of HANARO will be maximized in every area of a research reactor.

Acknowledgement

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