Status of Activities on the Unresolved Licensing Issues for HANARO

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Abstract

HANARO is a light-water-cooled and heavy-water-reflected research reactor designed to be operated at full power of 30 MW_{th}. When the reactor operating license was issued for HANARO in 1995, there were imposed two licensing conditions related to its rated operating power; the fuel power rating and the CHF prediction. The HANARO fuel design was based on AECL's tests in NRU. The Korean Institute of Nuclear Safety (KINS) requires KAERI to get more experimental data at higher linear heat rates which would prove the fuel integrity. For the analysis of CHF during steady state and transient events, COBRA-IV-I/KMRR was used. KINS requires KAERI to perform the further validation of the CHF analysis method. In this paper, the status of activities to resolve these issues and the future plans are described.

1. Introduction

HANARO is a light-water-cooled and heavy-water-reflected research reactor designed to be operated at full power of 30 MW_{th}. The compact core as shown in Fig. 1 results in high power density and high neutron flux. The hybrid-type core is composed of inner and outer core. The inner core, 50 cm in effective diameter and 1.2 m in height, has 23 hexagonal and 8 circular flow channels. Each hexagonal flow channel formed by a hexagonal flow tube is loaded with a hexagonal fuel bundle which has 36 fuel elements. The circular flow channel formed by a circular flow tube is loaded with a circular fuel bundle which has 18 fuel elements. Outside the circular flow tube, a hafnium control or shut-off shroud tube can be moved up and down for the control and shutdown of the reactor. Three out of 23 hexagonal flow channels are for the fuel and material test facilities. The outer core consists of eight circular flow channels embedded in the reflector vessel whose effective diameter is 2 m and the height is 1.2 m. Four out of 8 outer flow channels are to be used as the irradiation sites while the remainders are used as the circular fuel sites.

When the reactor operating license was issued for HANARO in 1995, there were two issues which brought the limitation for its rated power; the fuel power rating and the CHF issues. KINS required KAERI to get more experimental data at higher linear rate which would prove the fuel integrity. To resolve this issue, the fuel irradiation tests using the non- instrumented bundle and the instrumented bundle have been performed in the HANARO. For the analysis of CHF during steady state and transient events, COBRA-IV-I/KMRR was used. KINS required KAERI to perform the further validation of the CHF analysis method. For the resolution of this issue, the code modification and the validation using the experimental data have been performed.

2. Fuel Irradiation Test

2.1 Progress and Plan

The brief description of the irradiation was given in the last IGORR meeting[1]. For the verification of fuel performance, KAERI relied on the AECL's experimental data. During the basic design stage of the HANARO, the maximum linear heat generation rate(LHGR) from the fuel element was well below its maximum value which was experienced in the AECL's mini element tests. However, in the detail design stage, it was revealed that the maximum LHGR at full power would be quite close to the experienced maximum value when the uncertainty in physics calculation was considered. Thus, from 1993, the fuel irradiation test plan was discussed to help the licensing activity. Many options were considered and they were;

- Irradiation test at NRU and PIE at AECL
- Irradiation test at NRU and PIE at KAERI

- Irradiation test and PIE at another foreign reactor
- Irradiation test at HANARO and PIE at IMEF of KAERI

Following the evaluation of these options, the fourth option was selected. The bases for this decision were;

- HANARO would provide the exact boundary condition for the fuel performance evaluation, and
- the technical capability for the fuel irradiation test and PIE technique can be brought up by performing the test in KAERI.

The project was launched in May 1994. The test requirements for the project were;

- to show that the fuel performance is guaranteed at the LHGR higher than 130 kW/m,
- to get the experimental data required for the validation of physics code and T/H code, and
- to provide the samples enough for the evaluation of fuel properties as burnup.

As a first step of project, several members visited AECL and JAERI to learn their experience in fuel irradiation test and to discuss the help from them. Throughout the discussion on the design of test bundles and PIE plan, two types of test bundles were selected; Type A and Type B bundles. The top view of Type B bundle is shown in Fig. 2. The overall shapes of the test bundles are the same as the hexagonal fuel bundle. The Type A bundle is the non-instrumented test bundle and its shape is the same as type B bundle. It was designed to have six fuel elements - one for each hexagon surface and three hollow tube to accommodate the insertion of Au and Ni wires for the neutron flux measurement. The Type A bundle was fabricated by AECL. The Type B bundle is the instrumented test bundle. It has seven SPND's for neutron flux measurement, one SPGD for gamma flux measurement, four thermocouples for the subchannel exit temperature measurement. A guide tube is provided for the protection of instrument lines which should be hooked up to the reactor pool top. The fuel elements for Type B bundle was fabricated by AECL and the fabrication of the other parts and the assembling was done in Korea.

The two Type A test bundles were loaded in IR sites and the irradiation started in Nov. 1995. One of them was discharged at 54 atomic percent(a/o) burnup of initial fissile content. The target burnup of remaining one is 85 a/o and is still in the core. Table 1 shows the planned PIE tests to evaluate the fuel properties and the performance. The Type B bundle was loaded at CT site in Aug. 1996. During the irradiation, the guide tube for Type B bundle was supported by the robot arm attached to the pool liner. However, the vibration of the guide tube was observed and the bundle was unloaded shortly. To find the resolution for this vibration problem, natural frequency measurement in air, in-core vibration test and the numerical analysis were performed. By these investigations, it was concluded that an extra support within the chimney should be prepared. Thus, the extra support is being designed and the test will be resumed after the extra support is prepared. The extra support will be used for the fuel irradiation test, instrumented capsule test and RI production rig.

2.2 Available Experimental Data and Comparison with Calculation

During the physics commissioning test[2], the thermal and fast neutron flux in Type A bundles were measured by activation method using the Ag and Ni wires. The measured activity distributions were in good agreements with the MCNP calculations as depicted in Figs. 3 and 4 for the thermal neutron flux and for the fast neutron flux, respectively. In Fig. 5, the axial flux distribution measured by the SPND's in Type B bundle is compared with the VENTURE prediction at 22 MW power. The subchannel exit temperature measurement result is described in the other section with the T/H code prediction results.

3. Validation of CHF Analysis Method

From the discussion with KINS during license application, several issues on the CHF analysis were raised. The main issues were;

- the method applied to the consideration of the physics calculation uncertainties in the T/H calculation,
- the deficiencies in the validation of the hydraulic calculation model in COBRA-IV-I/KMRR, and

- the uncertainties in the bundle CHF analysis.

For the first item, the uncertainty of the physics calculation was treated as a factor in the determination of the design limit CHFR. KINS asked to deal it with separately by means of increasing the nuclear peaking factor for T/H design by the amount of its uncertainty. As for the second item, the regulatory body asked more experiments for which the exact fuel geometry is used. The biggest issue was the last item. They believed that the number of the bundle CHF data were too small to show that our CHF prediction method would correctly predict the CHF in a bundle geometry. Throughout the hot discussion about the above matters, it was finally decided that further validation of the CHF analysis system should be performed.

After the operating license was obtained, a plan was established to recover the CHF penalty[3]. The key activities included in this plan were;

- the verification of the uncertainties in the physics calculation,
- the verification of the uncertainties of the engineering variables,
- the extended subchannel velocity measurement experiment,
- the measurement of the subchannel exit enthalpy in the fuel irradiation test, and
- the modification of the T/H models in used in the subchannel analysis.

In Table 2, the uncertainties of physics calculation for design are compared with them evaluated using the commissioning data. As for the peaking factor within an assembly, which is believed to bring lots of conservatism in design calculation, its uncertainty will be evaluated by the rodwise gamma scanning. The verification of the uncertainties of the engineering variables is completed. The extended subchannel experiment has been completed[4]. For the subchannel analysis, MATRA[5], which is the modified version of COBRA-IV-I by KAERI, is being used and the validation of its hydraulics model was made using the extended subchannel experiment results. The best method for the loss coefficients of the fuel end plates and the spacer were selected. In Fig. 6, the measured subchannel velocity distribution for the 18 element assembly is compared with the prediction by MATRA. The thermal diffusion coefficient (TDC) is a important parameter for the subchannel analysis. A proper value of TDC was selected by comparing the measured subchannel exit temperatures from Type B irradiation test with the MATRA calculation results. The measurement results are compared with the prediction in Fig. 7. As for the bundle CHF analysis, the new test data was given to KAERI by AECL based on an agreement for the cooperation in research reactor field. A subcooled model for the HANARO analysis was implemented to MATRA and the analyses of the bundle CHF test data are being performed.

4. Summary and Future Plan

In this paper, the current status of the activities related to the unresolved licensing issues for the HANARO was described. The remaining activities for the fuel irradiation test is the continuation of the irradiation of Type A and B test bundles and the PIE of the test fuels. As for the CHF issue, the analyses for the steady state operation and the transient conditions will be performed to clear the conditioned license. These activities will be made with the target of resolution in 1999.

References

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[2] B.C. Lee and C.G. Seo, "Thermal and Fast Neutron Reaction Rates in HANARO", proceedings of ASRR-5, pp.117-122, May 29-31, 1996, Taegon, Korea.

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[5] Y.J. Yoo and D.H. Hwang, "Development of MATRA-α version for Subchannel Ananysis, proceedings of KNS Autumn Meeting, pp.579-584, Oct. 24-25, 1997, Taegu, Korea.

Table 1. Post Irradiation Examination Plan for HANARO Fuel

BN ID	rod ID	BU (NDT)	DT							mech. test	RFL γ-spec.	act. analy.	RMs
			L	ΔV^*	oxide thick.	react. layer	bub. dis.	therm. charact.	BU				
A (40at%) (type B)	1	●	T	●	●	●	●	●	●				
			M	●	●	●	●	●	●		●		
			B	●	●	●	●	●	●				
	2	●	T										
			M								●		arch.
			B										
	3	●	T							●		●	
			M							●	●		
			B							●			
	4	●									●		arch.
	5	●									●		arch.
	6	●									●		arch.
B (60at%) (type A)	1	●	T	●	●	●	●	●	●				
			M	●	●	●	●	●	●		●		
			B	●	●	●	●	●	●				
	2	●	T	●	●	●	●	●	●				
			M	●	●	●	●	●	●		●		
			B	●	●	●	●	●	●				
	3	●	T							●		●	
			M							●	●		
			B							●			
	4	●	T							●			
			M							●	●		
			B							●			
	5	●									●		arch.
	6	●									●		arch.
C (85at%) (type A)	1	●	T	●	●	●	●	●	●				
			M	●	●	●	●	●	●				
			B	●	●	●	●	●	●				
	2	●	T										
			M										arch.
			B										
	3	●	T	●	●	●	●	●	●		X	X	
			M	●	●	●	●	●	●				
			B	●	●	●	●	●	●				
	4	●								●			
										●			
										●			
	5	●											arch.
	6	●											arch.

BN : bundle, BU : burnup, RMs : remarks, arch. : archives
T : top, M : middle, B : bottom
* : The measurements of length, diameter, density are included.

Table 2. Uncertainties in the Physics Calculation for HANARO

	Assembly power peaking factor	Axial power peaking factor	Peaking factor with an assembly
Design Calculation	10 %	Not considered as the calculation was assumed to be conservative.	Not considered as the conservative value was used.
Commissionig Results	6.1 %	3.7 %	Not available yet

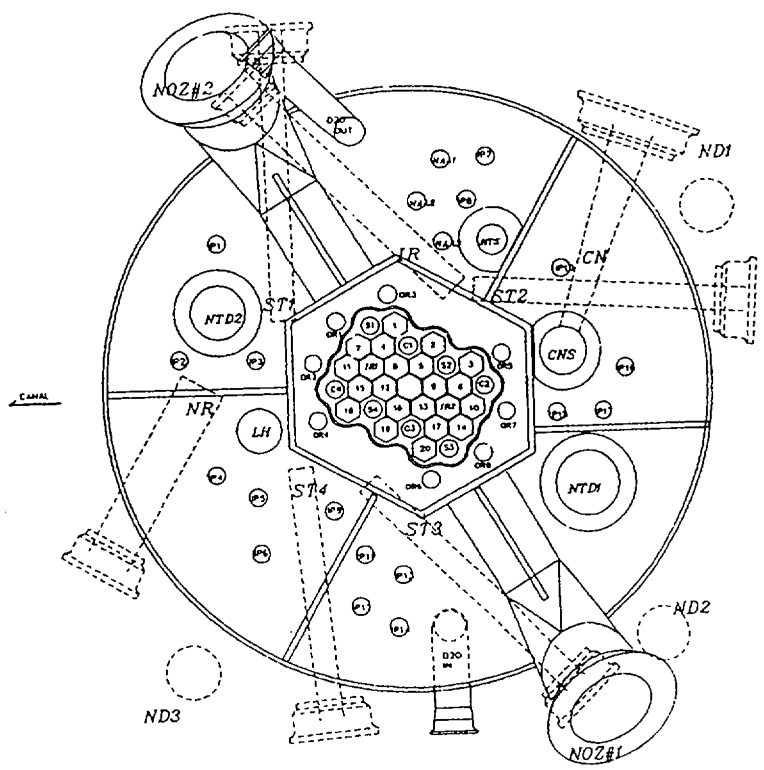

Fig. 1 HANARO Core Configuration

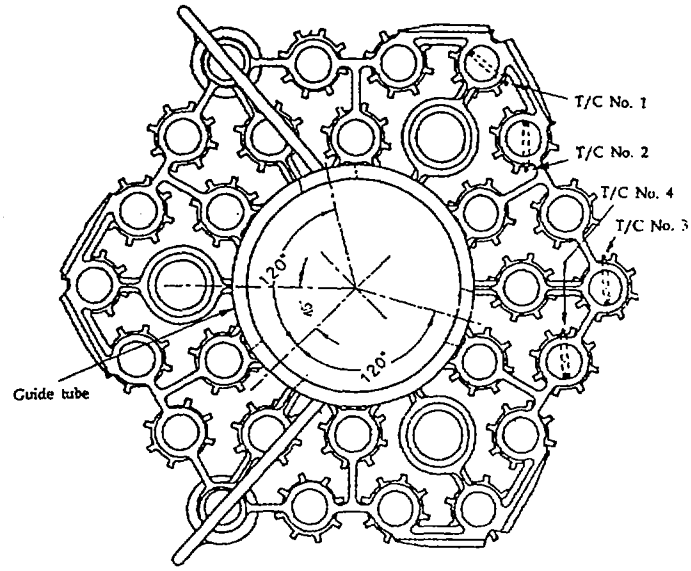

Fig. 2 Top View of Type B Test Bundle

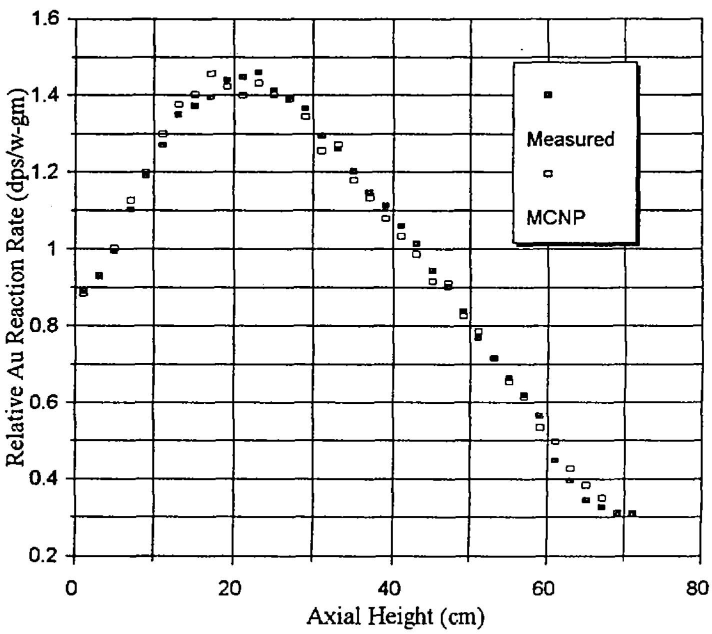

Fig. 3 Comparison of the measured reaction rate of Au wire with MCNP calculation for activation in Type A bundle at IR1 site

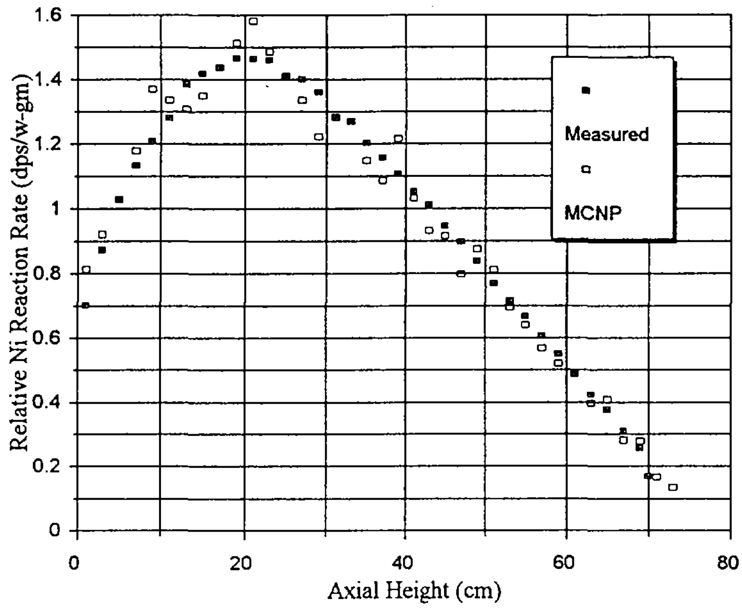

Fig. 4 Comparison of the measured reaction rate of Ni wire with MCNP calculation for activation in Type A bundle at IR1 site

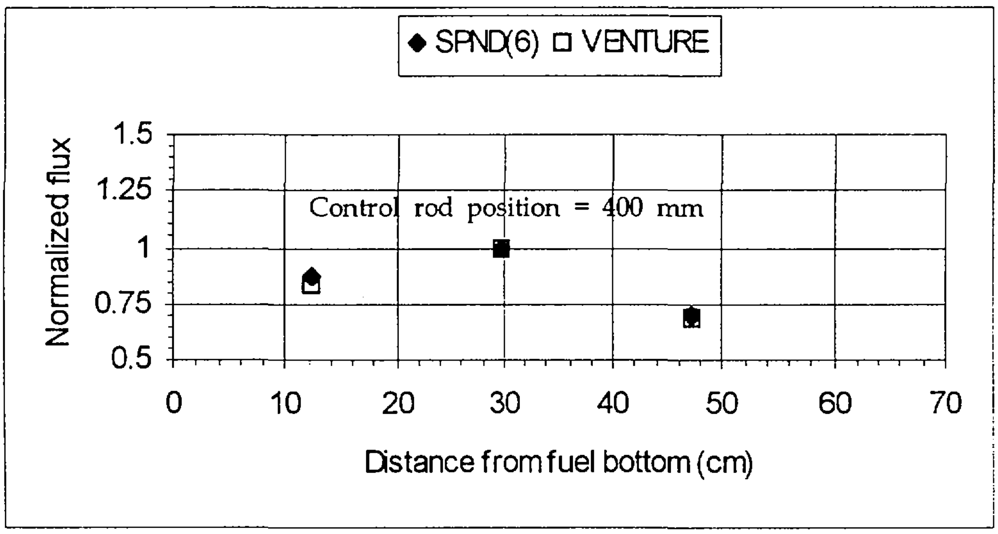

Fig. 5 Axial Flux Distribution for Type B test bundle

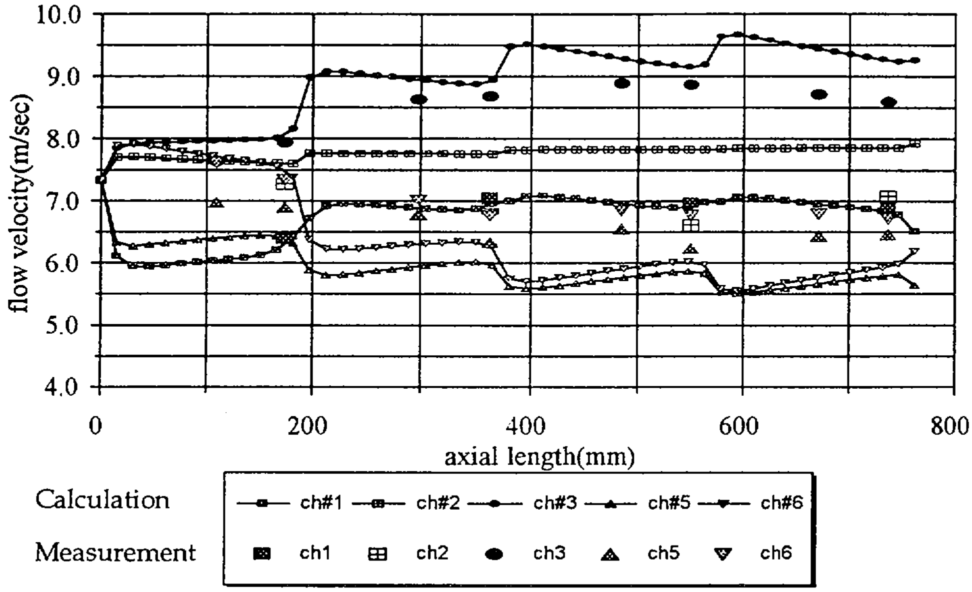

Fig. 6 Subchannel Velocity Distribution in 18 Element Assembly

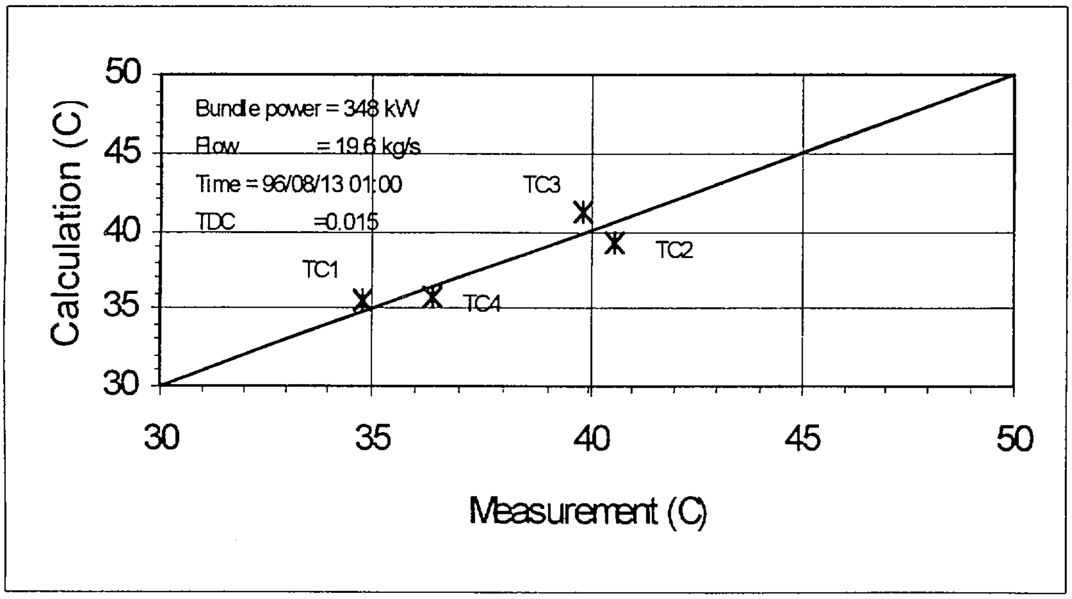

Fig. 7 Subchannel Exit Temperature Ditribution for Type B Bundle