The Initial Criticality and Nuclear Commissioning Test Program at HANARO

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ABSTRACT

The construction of the Korea Multipurpose Research Reactor - HANARO of 30MW, developed by Korea Atomic Energy Research Institute, was completed at the beginning of this year. The first fuel loading began on February 2, 1995, and initial criticality was achieved on February 8, when the core had four 18-element assemblies and thirteen 36-element assemblies. The critical control rod position was 600.8 mm which represents excess reactivity of 0.71 $. Currently the nuclear commissioning test is on going under the zero power range.

This paper describes the initial criticality approach of the HANARO, and its nuclear commissioning test program.

1. Reactor Description

The HANARO is an open-tank in pool type research reactor cooled by upward forced convection of light water. The fuel is a rod type made of co-extruded U_3Si-Al with finned aluminum cladding. The fuel has a nominal composition of 61.4 w/o U_3Si and 38.6 w/o Al and its enrichment is 19.75 w/o ^{235}U in total uranium. The fuel elements are clustered to form a fuel assembly. Two types of fuel assemblies are used in the HANARO : 18-element and 36-element assemblies. The 36-element fuel assembly is the primary fuel assembly. It is loaded into the hexagonal flow tube in the main core region of the reactor. The 18-element assemblies are placed in the circular flow tubes.

The reactor structure is made up of five main components as shown in Fig. 1 : the inlet plenum supporting the reactor tank and distributing inlet coolant, the lower grid plate holding the fuel assemblies and experimental facilities, the reactor tank, the outlet chimney mixing coolant passed through individual flow tubes and bypass flow, and the flow tube channels.

As shown in Fig. 2, the core consists of three parts : the inner core, the outer core and the reflector in the radial direction. The compact inner core, inside the inner shell, looks like a honeycomb, which is composed of 23 hexagonal flow tubes and 8 circular ones. The light water flows inside and outside of the flow tube to remove the generated heat. A suitable fuel assembly can be loaded in each flow tube. Three sites(CT, IR1 and IR2) of 23 hexagonal flow tubes are reserved for material irradiation tests requiring high fast neutron flux. These site shall hold experimental device on duty or aluminum dummy assemblies off duty.

There are eight neutron absorber tubes - four CARs(Control Absorber Rods) and four SORs(Shut Off Rods). During the normal operation condition, CARs regulate neutron power and SORs are at the fully withdrawn state and shut down the reactor power rapidly in case that any reactor trip signal is initiated. While CAR is operated by stepping motor, SOR is operated by hydraulic power.

The inner core is surrounded by the inner shell of zircaloy which separates the inner core and reflector. The inner diameter of zircaloy reflector tank is 2.0 m and its height is 1.2 m. In the reflector adjacent to the inner shell, there are eight circular flow tubes called as the outer core. D_2O is used as the reflector material to maximize the region where the high thermal flux is available. There are 25 vertical holes and 7 horizontal beam tubes in the reflector tank.

2. Initial Criticality

2.1 The Neutron Detection System for Nuclear Commissioning Test

Although there are six fission chambers at the outside of the reflector tank for the power monitoring, they could not be used for initial criticality approach due to their very weak responses.

The neutron detection system for the nuclear commissioning tests was composed of six neutron detectors as shown in Fig. 3, which consist of two fission chambers, two BF_3 counters and two CICs(Compensation Ion Chambers), respectively. Two fission chambers and two BF_3 counters were used to measure neutron count rate in the course of the fuel loading. Two CICs provide signals for reactivity meter. These detectors were placed in the irradiation holes in the reflector tank as shown in Fig. 2.

2.2 Approaching to Initial Criticality

The first fuel loading into the core began on February 2, 1995. The fuel was sequentially loaded from center to outside of the core as shown in Fig. 4. At first, four 18-element fuel assemblies were placed into the control absorber sites and this condition was used as the initial state for inverse multiplication measurement. The count rates were measured under the four reactor conditions to guarantee criticality safety during fuel loading:

(1) Condition 1 : All SORs down, all CARs down
(2) Condition 2 : All SORs up, all CARs down
(3) Condition 3 : All SORs up, all CARs 350 mm (half) up
(4) Condition 4 : All SORs up, all CARs up

The count rates of fission chambers were about 0.6 cps and those of BF_3 counters were about 708 and 1320 cps, respectively under the Condition 4 of initial state. Fig. 5 shows 1/M curves vs. the loading of 36-element fuel assemblies plotted for the four reactor conditions. From the 1/M curve, we can deduce that the minimum number of 36-element assemblies for initial criticality will be thirteen.

After loading 13th 36-element assembly, the count rate was measured when all SORs were fully up and four CARs are being withdrawn step by step to search critical CAR position. Fig. 6 shows 1/M curve vs. CAR position. This curve predicts that the critical CAR position will be near 600 mm.

At last, the HANARO achieved initial criticality on February 8, 1995 with the following core configuration:

(1) All SORs fully out
(2) All CARs 600.8 mm out
(3) Four 18-element fuel assemblies, thirteen 36-element fuel assemblies in the core
(4) Uranium mass in the core : 33.46 kg
(5) Pool water temperature : 16.2 ℃
(6) Excess reactivity : 0.71 $

2.3 Comparison of Analysis and Experimental Results

The multiplication factor of initial critical core in the condition of all rod out, was 1.005 from the experiment. The core physics calculations using design codes, WIMS-VENTURE and MCNP, predicted criticality. The MCNP predicted k_{eff} of 1.0098 with ENDF/B-IV and 1.01802 with ENDF/B-V, WIMS-VENTURE predicted as 1.02239. Though it had been expected that WIMS-VENTURE model used for the HANARO design would overestimate k_{eff}, the the overestimation by MCNP with ENDF/B-V is much far from our expectation. Thereafter, when fuel assemblies are added, the tentative comparisons show that differences between calculations and experiment are consistent.

3. Nuclear Commissioning Test Program

There are four objectives for the reactor physics experiments.

a. Design verification
b. The production of reactor characteristic data for operation and utilization
c. Establishment of the procedures for routine reactor physics experiments
d. Training of the operators

3.1 Nuclear Commissioning Tests at the Zero Power Range

After initial criticality, additional fuel assemblies has been loaded to construct the first operational core which has eight 18-element fuel assemblies and sixteen 36-element fuel assemblies. The CAR worth, fuel reactivity worth, shutdown margin, excess reactivity has been measured to verify design data whenever a fuel was added in the core. Currently, the construction of first operational core has been completed and hereafter, the following nuclear commissioning tests at the zero power range will be performed by September this year:

a. SOR and CAR reactivity worth measurement
b. Noise analysis to measure the kinetics parameters and fission power
c. γ-flux distribution measurement
d. Void coefficient measurement
e. Reactivity worth measurement for irradiation samples
f. Thermal flux distribution measurement and power calibration
g. Fast neutron flux distribution measurement
h. Assemblywise power distribution measurement
i. Coolant temperature coefficient measurement
j. Transfer function measurement in the zero power range

3.2 Reactor Commissioning Tests at The Power Range

Following tests will be carried out at various power level up to 15MW which is the full power of the first cycle:

a. Power defect measurement
b. Verification of heat removal capability and thermal power calibration
c. Transfer function measurement
d. Verification of heat removal capability for the case of the Loss-of-Offsite Electric Power
e. Xe and Sm reactivity worth measurement
f. Measurement of long term operational characteristics

4. Future Plan

Near the end of this year, The HANARO will meet the end of the first cycle. Some physics experiments will be performed to verify design data at the end of cycle and the second cycle core will be constructed by adding two 36-element fuel assemblies and two 18-element ones as per the fuel management plan. Its cycle length is to be 60 days at 24 MW. The third cycle is the first full loaded core, which is made by adding two 36-element fuel assemblies and two 18-element assemblies more. After the third cycle, HANARO will be operate routinely at the design rated power 30MW. Up to the 10th cycle which is expected to reach equilibrium core state, we will make rather extensive physics experiments to tune our core management tools.

REFERENCES

1. C. S. Lee, Commissioning Report on Fuel Loading and Initial Criticality, TP-RPT-F-07, 1995.
2. H. R. Kim, W. S. Park, et al., " The In-core Fuel Management of the KMRR ", KM-031-RT-K045, 1993.
3. D. S. Lim, "The Set-up Procedure of the Neutron Detection System for Reactor Commissioning", Reactor Performance Test Procedure of the HANARO, TP-RPT-F-01, 1993.
4. C. S. Lee, " Fuel Loading and Initial Criticality Procedure ", Reactor Performance Test Procedure of the HANARO, TP-RPT-F-07, 1993.

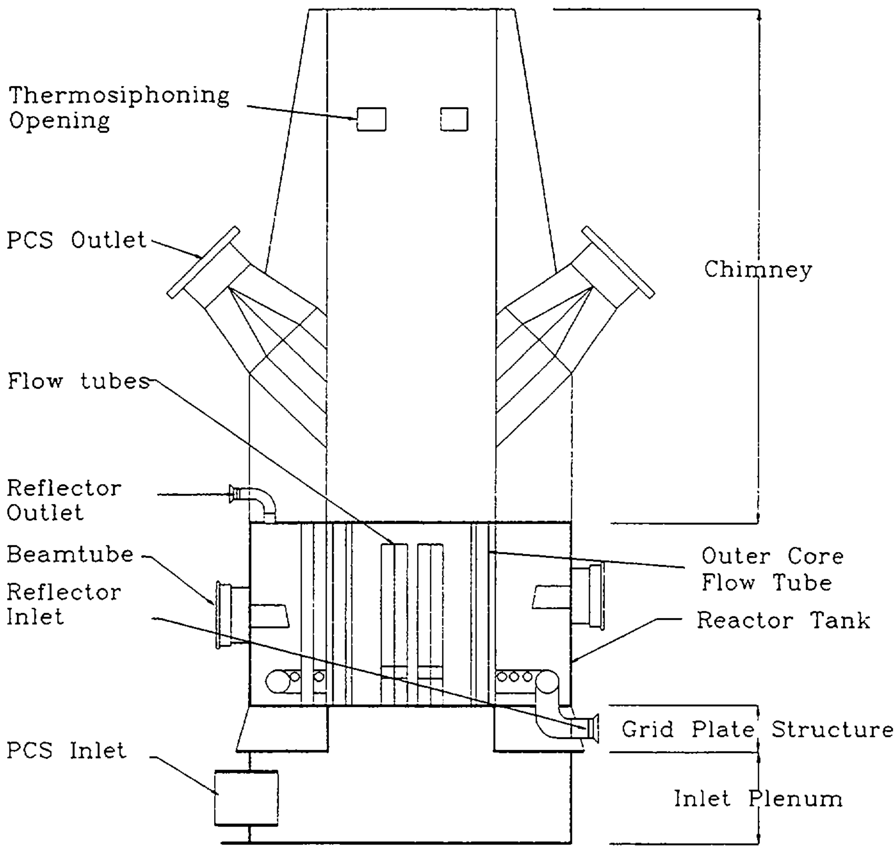
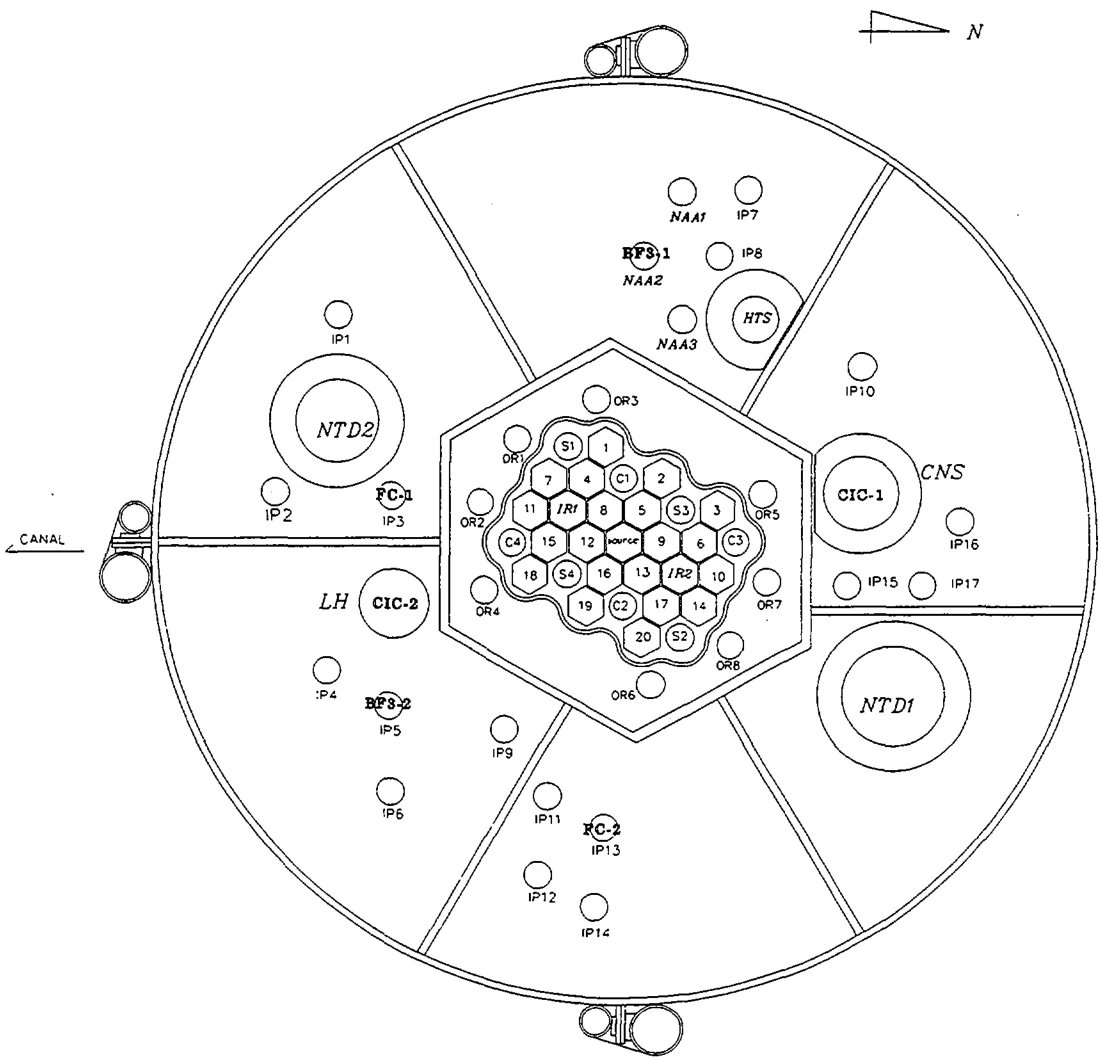


Fig. 1 Vertical View of the HANARO Reactor Assembly



1 - 20	:	36-element fuel assembly sites
S1 - S4	:	SOR sites
C1 - C4	:	CAR sites
OR1 - OR8	:	Outer core sites
IP1 - IP17	:	Isotope production hole
NAA1 - NAA3	:	Neutron activation analysis hole
HTS	:	Large NAA hole
LH	:	Hole to install the fuel test loop
NTD1 - NTD2	:	Neutron transmutation doping hole
CNS	:	Cold neutron source housing hole

Fig. 2 Plan View of the HANARO Core

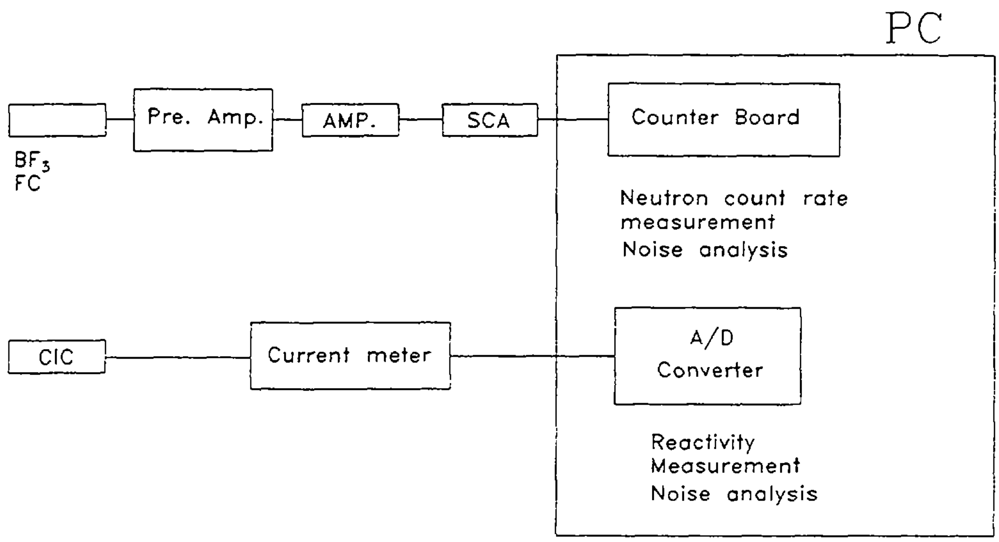


Fig. 3 The Schematic Diagram of the Neutron Detection System

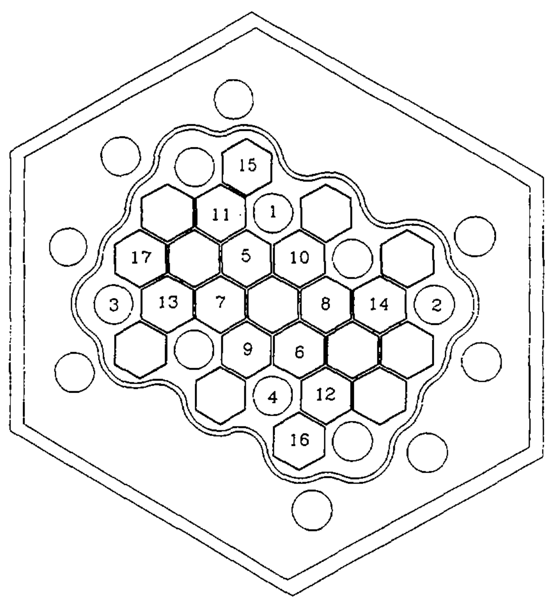


Fig. 4 The Fuel Loading Sequence of the Initial Critical Core

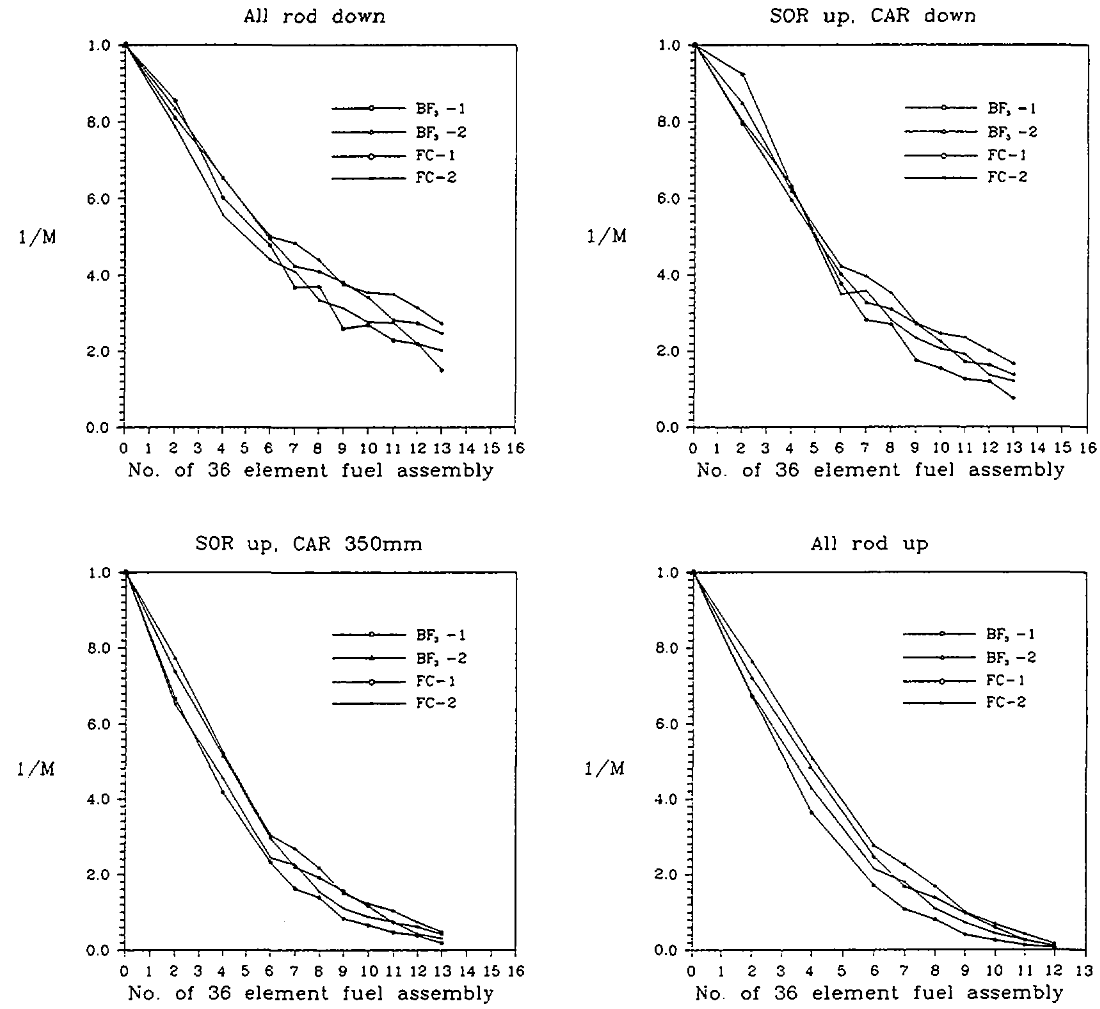


Fig. 5 1/M Curves vs. No. of 36-element Fuel Assembly Loaded

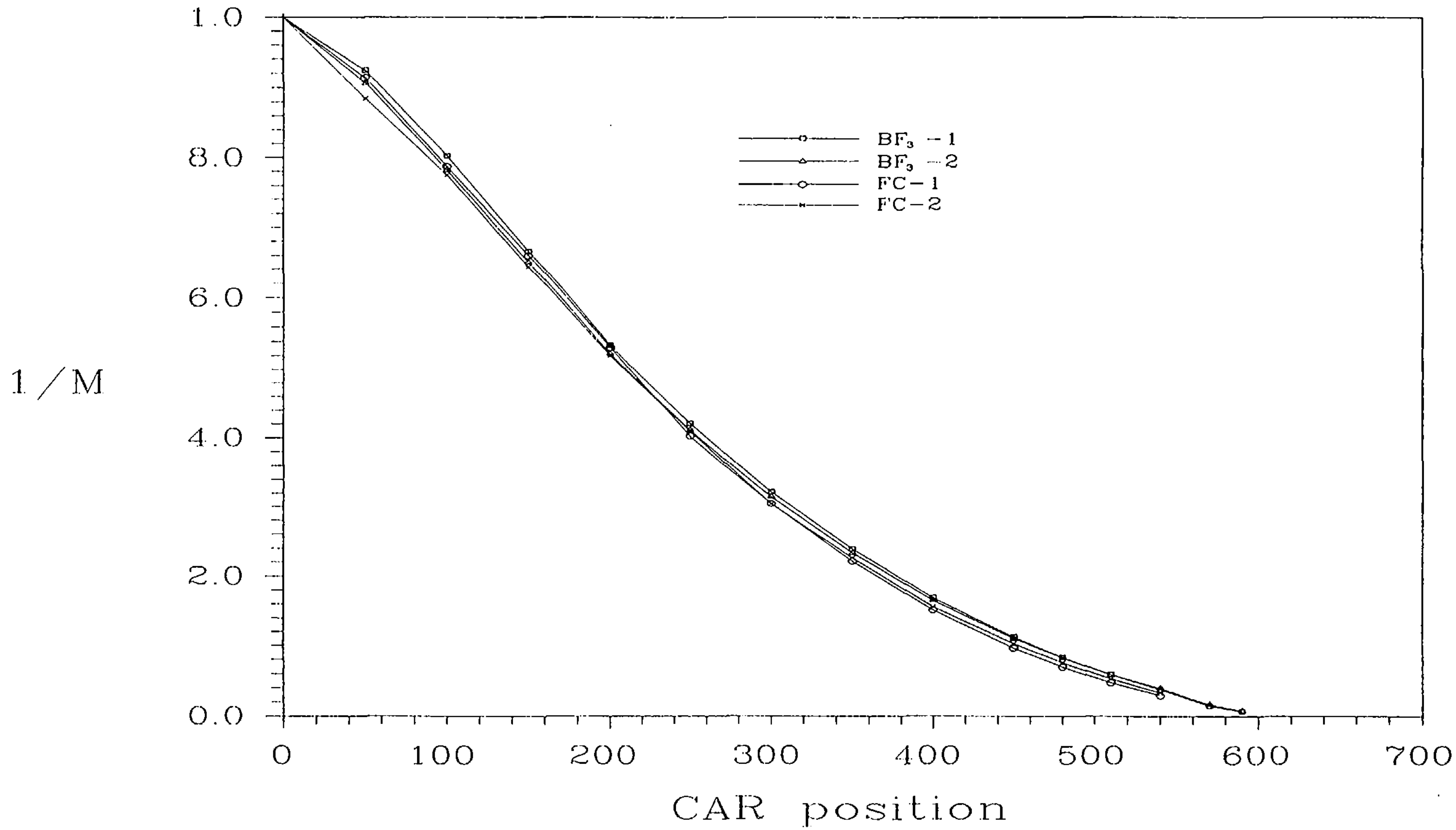


Fig. 6 1/M Curves vs. CAR Position