2. NUCLEAR DESIGN

2.1 Summary

The HTTR is a graphite moderated thermal reactor with low-enriched uranium dioxide fuel. The functions of the reactivity control system are determined considering the operational conditions, and the reactivity balance is planned so that the design requirements are fully satisfied. Moreover, the reactivity coefficients are evaluated to confirm the inherent safety characteristics of the reactor. Ninety-nine percent of the total power is produced in the active core and the residual 1% in the reflector region. Ninety-five percent of the power in the active core is produced in fuel rods and 5% in graphite blocks, respectively. The power distribution is determined to suppress the maximum fuel temperature as much as possible.

The mean neutron lifetime is about $0.7 \times 10^3$ second and the change is small through out the burnup cycle. The delayed neutron fraction is about 0.0065 at beginning of life (BOL) and about 0.0047 at end of life (EOL). The power coefficient of reactivity is negative because of the negative Doppler coefficient. Therefore, the power excursion in abnormal reactivity insertion accidents is suppressed to sufficient extent. The oscillation of the power distribution does not arise.

2.2 Design Requirements

The nuclear design must satisfy the following requirements.

(1) Excess reactivity
   Excess reactivity must be determined taking into account the following effects.
   1) Temperature increase from the cold shutdown state to the rated power operation state
   2) Build-up of fission products (FPs), such as $^{133}$Xe, $^{149}$Sm and others
   3) Burnup of fuel
   4) Margins including the irradiation tests
   5) Uncertainty for nuclear calculations

(2) Reactor shutdown margin
   The control rods (CRs) must be so designed as to provide a reactor shutdown margin of more than 0.01 $\Delta$ k/k even if one pair of CRs having the maximum reactivity worth is completely withdrawn and can not be reinserted. The reserved shut down system (RSS) must be designed to allow for a reactor shutdown margin of more than 0.01 $\Delta$ k/k even if the CR system is not available.

(3) Reactivity addition rate
   The maximum reactivity addition rate with the CRs must be limited to such extent that a related power excursion does not impair the integrity of the core, the reactor internal structures, the primary cooling system, etc. In order to satisfy these conditions, the CR system shall be so designed that the maximum reactivity addition rate does not exceed $2.4 \times 10^4$ $\Delta$ k/k/s even if the CRs are withdrawn with the permissible maximum speed.

(4) Reactivity coefficient
   An important reactivity coefficient is the power coefficient of reactivity which is dominated by the Doppler and the moderator temperature coefficients. The reactor core must have a negative reactivity feedback characteristic, which damps the power level change. To achieve this condition, the reactor core must be designed in such a way that the power coefficient of reactivity is negative
for any operation condition.

(5) Power distribution

The power distribution must be so determined that the fuel temperature does not exceed the limited value during normal operation and anticipated operational occurrences (AOOs). To obtain this condition, the fuel and burnable poison (BP) must be loaded so that the maximum fuel temperatures are kept as low as possible.

(6) Stability

The core must be so designed as to have a damping characteristic which prevents any oscillation of the power distribution as well as the power level itself.

(7) Burn-up

The maximum value of the average burnup in a fuel element must not be over 33,000MWD/t. This value is determined by fuel irradiation test data.

2.3 Analytical Method

The shutdown margin, CR worth, reactivity coefficient and power distribution are the most important characteristics which must satisfy the design requirements. Therefore, they should be evaluated with a nuclear design code system with sufficient accuracy. The calculation accuracy of the system was evaluated by comparing the calculated and measured values of the Very High Temperature Reactor Critical Assembly (VHTRC) experiment. The nuclear design code system for the HTTR and its accuracy are described hereafter.

2.3.1 Nuclear Design Code System and Calculation Model

The nuclear design code system for the HTTR consists of the computer codes DELIGHT\textsuperscript{[3,13,14]}, TWOTRAN-2\textsuperscript{[15]} and CITATION-1000VP\textsuperscript{[16,17]}. The program structure of the system is shown in Fig.2.1. DELIGHT is a one-dimensional lattice burnup cell calculation code which has been

![Diagram of code system flow](image)

**Fig. 2.1** Structure of the nuclear design code system for HTTR