Preliminary Neutronic Analysis of 150 MWt High-Temperature Gas Reactor to Produced Electricity in Small Area

Nining Yuningsih¹ and Dwi Irwanto²
¹Magister of Physics Program, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, West Java, Indonesia
²Nuclear Physics and Biophysics Research Division, Faculty of Mathematics and Natural Sciences, Institut Teknologi Bandung, Bandung, West Java, Indonesia

Email: nining.1924@gmail.com*

Abstract. There are small areas in Indonesia with insufficient electricity. High-Temperature Gas Reactor (HTGR) is a promising nuclear power plant that can be used in such areas as its capability to produce electricity and co-generation applications. A preliminary study on the neutronic aspect of the 150 MWt HTGR design is performed in this research. High Temperature Engineering Test Reactor (HTTR) is used as a basic model. The calculation was performed by Standard Thermal Reactor Analysis Code (SRAC) code, and Japanese Evaluated Nuclear Data Library (JENDL) 4.0 as nuclear data library. As a result, by increasing HTTR fuel assembly geometry to 1.5 times its original and using higher uranium enrichment, the reactor can be operated for five years.

1. Introduction
HTGR is a helium gas-cooled fission reactor that is considered one of the future nuclear power plants. Based on the neutron energy used in the core, there are two types of HTGR, namely thermal and fast HTGR. Many kinds of research have been performed for Gas Fast Reactor [1,2] and thermal reactor, including pebble type and block type HTGR [3–5]. HTGR has a core outlet temperature of 950 - 1000 degrees Celsius, the highest temperature of all nuclear reactors. This high temperature can be used to produce electricity and as a source of heat for cogeneration reactors [6]. AREVA that makes commercial HTGR is launching ANTARES to meet the demands of the electricity and heat processing industry[7]. Japan, through JAEA, has developed a High-Temperature Engineering Test Reactor (HTTR) with a power of 30 MWt and a temperature of 950 degrees Celsius, whose operations began in 1998 and continue to be successful until now [8–10].

Nuclear power that combines heat and power applications such as district heating, seawater desalination, and heat application in industrial processes becomes a highly potential consideration in the coming years. Small and operationally simple, HTGR is also suitable for remote or developing areas, such as many areas in Indonesia.

In this research, a preliminary neutronic study of 150 MWt HTGR that has long operation periods will be performed. Modification of fuel assembly geometry, fuel enrichment, and composition in the reactor core will be analyzed and optimized using HTTR as a basic design.
2. Calculation Method
In the present study, 150 MWt block-type HTGR will be calculated and analyzed using the SRAC code version 2006 [11] and based on JENDL 4.0 as evaluated nuclear data library [12]. The calculation is done in two stages. Fuel assembly calculation is done using PIJ, while core calculation is done using CITATION.

The basic model is based upon the High-Temperature Engineering Test Reactor (HTTR) design. A horizontal view of HTTR’s core cross-section is shown in figure 1. Modifications were made for several important parameter designs, such as fuel enrichment, power level, and geometry size, to meet the operation target. Table 1 shows the primary design parameters used in the present study.

![Figure 1. Horizontal view of HTTR’s core cross-section [13].](image)

| Reactor Parameters                  | Unit       | Value       |
|-------------------------------------|------------|-------------|
| Power (thermal)                     | MWt        | 150         |
| Core structure                      | -          | Graphite    |
| Equivalent diameter of the core     | M          | 2.76 - 3.68 |
| Effective height of the core        | M          | 2.9         |
| Fuel uranium enrichment             | wt %       | 15-17.5     |
| Coolant material                    | -          | Helium gas  |
| Flow direction                      | -          | Downward    |
| Quantity of fuel block              | -          | 150         |
| Quantity of fuel column             | -          | 30          |
| Quantity of control rods pairs      | -          | 7/9         |
3. Calculation Results and Discussion
One of the problems to be solved for nuclear power plants operating in a remote areas is operation time. In many cases, a longer operating time is required to optimize the reactor operation's economic values and practicality. To find the best configuration that leads to the long operation time, a set of parameter surveys was needed to be investigated. Figure 2 shows the variation of fuel enrichment and its effect on the infinite multiplication factor and operation time.

![Figure 2. Effect of fuel enrichment to infinite multiplication factor and operation time.](image)

It is shown in figure 2 that higher fuel enrichment leads to longer operation time, as expected. The minimum fuel enrichment that makes the reactor critical for more than two years is 13\% enrichment. Moreover, more operation time is potentially obtained using 15-17\% fuel enrichment. These values are rationally possible compared to a higher enrichment of 18-20\%, as higher enrichment means a higher cost is needed.

The reactor operation time is expected to increase further as one increases the fuel quantity by modified its geometry. In the present study, the assembly's size is increased from 1.3 – 1.6 times that of HTTR's fuel assembly. The fuel assembly's configuration is shown in figure 3, while the fuel block configuration inside the reactor core is shown in table 3.
**Figure 3.** Configuration of fuel assembly.

**Table 2.** Configurations of fuel blocks in core [13].

| Axial Layer | Items                      | Fuel Zone |       |       |       |
|-------------|---------------------------|-----------|-------|-------|-------|
|             | Fissile Enrichment (%)    | 1         | 2     | 3     | 4     |
| 3           | 16.75                     | 17.25     | 17.50 | 17.75 |
|             | Fuel rods quantity        | 33        | 33    | 31    | 31    |
|             | BP type                   | HI        | HI    | HI    | HI    |
| 4           | 16.00                     | 16.50     | 17.00 | 17.25 |
|             | Fuel rods quantity        | 33        | 33    | 31    | 31    |
|             | BP type                   | HII       | HII   | HII   | HII   |
| 5           | 15.50                     | 16.00     | 16.25 | 16.50 |
|             | Fuel rods quantity        | 33        | 33    | 31    | 31    |
|             | BP type                   | HII       | HII   | HII   | HII   |
| 6           | 15.00                     | 15.25     | 15.50 | 15.75 |
|             | Fuel rods quantity        | 33        | 33    | 31    | 31    |
|             | BP type                   | HI        | HI    | HI    | HI    |
| 7           | 15.00                     | 15.25     | 15.50 | 15.75 |
|             | Fuel rods quantity        | 33        | 33    | 31    | 31    |
|             | BP type                   | HI        | HI    | HI    | HI    |
Figure 4 shows the effect of increased assembly geometry on the effective multiplication factor and operation time. Using 1.3 times HTTR’s assembly geometry, the reactor could operate for three years, while using 1.4 times HTTR’s assembly geometry, it increased to four years operation times. Data from figure 4 also shows that five years operation times could be obtained using 1.5 and 1.6 HTTR’s assembly geometry. From the calculation, it could be understood that 1.5 times HTTR’s assembly geometry gives the optimal value. It could have the longest operation times with as few as possible geometry, considering that higher geometry means a higher cost is required.

4. Conclusion
A preliminary neutronic study of 150 MWt HTGR for long operation times was performed in the present research. Parametric surveys to investigate the effect of fuel enrichment on infinite multiplication factors and operation times were performed at the assembly level. The calculations show that at least 13% enrichment is needed to achieve two years of operation time. 15-17% fuel enrichment then selected as these values are rationally possible compared to higher enrichment of 18-20%, as higher enrichment means higher cost. Modification of fuel assembly geometry and its composition in the reactor core was the next parameters to be optimized. The calculation found that five years operation times could be obtained using 1.5 and 1.6 HTTR assembly geometry. 1.5 times HTTR assembly geometry gives the optimal value because it could have the longest operation times with as few as possible geometry.

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