THORIUM UTILIZATION IN A PEBBLE BED REACTOR

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ABSTRACT
Thorium reserves in the earth's crust are much more than those of uranium, which today measure about 1.5 million tonnes of reasonably assured resources, plus 3 million tonnes of estimated additional resources. These large amount of thorium reserves, also available in Turkey encourages to focus on the utilization of thorium.

The most remarkable applications of the use of thorium have been in high temperature reactors. The high temperature pebble bed reactor, which has been chosen as the basis for this study, is a close approximation of the thorium utilizing German reactor THTR. Pebble bed reactors have some unique features which are suitable to bum thorium, (i) The fuel is loaded in the form of coated particles, which are embedded in the graphite matrix of the fuel pebbles, allowing exceptionally high heavy metal bumups; and (ii) the continuous (on-line) fuel loading allows a high utilization factor.

The criticality search of the pebble bed reactor is computed by the use of the SCALE4.4 code, CSASIX and KENOVA modules. And the in-core fuel management is computed via SCALE4.4 code, ORIGEN-S module.

INTRODUCTION
The initial THTR core consists of a bed of randomly distributed 6cm diameter spherical elements. The bed is a mixture of fuel, graphite and absorber elements. Fuel consists of \((\text{ThU})_2\) fuel particles with a 400pm diameter micro-sphere (kernel) with two layers of PyC (PyroCarbon). The absorber elements contain boron and hafnium as neutron absorbers. The initial core is composed of:

- 358,200 (53%) fuel elements (FEs)
- 272,500 (40%) graphite elements (Ges)
- 43,500 (7%) absorber elements (AEs)

The initial core is designed as a radial two-zone core. The desired flux flattening is achieved by utilizing different mixtures for inner and outer zones of the core. The mixing ratio is:

- Inner zone \(\text{AE:GE:FE}=1:6:5\)
- Outer zone \(\text{AE:GE:FE}=1:6:12\)
UNIT CELL MODELLING

The THTR core is double heterogeneous; the fuel kernels having three regions - fuel, inner PyC, outer PyC - creates the first level of heterogeneity. The pebble made up of the fuel kernels, graphite matrix, and coating introduces the second heterogeneity. Furthermore, since the fuel elements are spherical and high in number, there are several complexities regarding the design of the core. This heterogeneity and complexity necessitate the use of Monte Carlo methods. KENOVa module of SCALE4.4 code was used to accomplish this task. KENOVa is an improved Monte Carlo criticality program with super-grouping.

Two different unit cells are defined to model the THTR core. These correspond to the inner and outer zones mentioned above. The unit cell for the inner zone is established as a 2x2x3 prism of spheres, and the outer zone consists of a 2x2x19 placement.

![Fig 1. Radial Two-Zone Core of THTR](image)

The KENOVa module\(^1\) is used to determine the multiplication factor for the infinite medium for two unit cells. The KENOVa module also computes the flux distributions for these unit cells. An interface program is used to determine the integrated group fluxes, which are the input parameters THERM, RES, FAST\(^1\) for ORIGEN-S. ORIGEN-S uses an HTGR cross section library to generate the concentration of fission products and actinide materials. The output of ORIGEN-S contains \(k_{OT}\) and fissile content as a function of burnup.

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\(^1\) See Section for Weight Factors for ORIGEN-S: THERM, RES, FAST
The reactivity as a function of burnup gives the discharge burnups of these two zones. This is done in the following manner:

\[
\frac{f_1}{f + f_2} \int_0^{B_d} \rho_i(B) dB + \frac{f_2}{f + f_2} B_d \int_0^{P_2} \rho_j(B) dB = 0
\]

where:

- \( f \): fraction of spherical elements in the inner zone.
- \( f_2 \): fraction of spherical elements in the outer zone.
- \( P_i \): the reactivity of inner zone unit cell.
- \( p_2 \): the reactivity of outer zone unit cell.
The core is made up of % volume outer zone and % volume inner zone. As a result of the studies, the discharge burnup is found to be approximately 7.163 MWd for the inner zone unit cell and 20.045 MWd for the outer zone unit cell.

$^{232}$Th is converted into a fissile isotope $^{233}$U that contributes in the power generation more than other fissile isotopes. In THTR, $^{239}$Pu and $^{241}$Pu have much less contribution in power generation than LWRs. This can be explained by low initial loading of $^{238}$U (less than $1\%$).

Fig. 4 The reactivity versus burnup curve for outer zone unit cell

Fig. 5 Change of $^{233}$U content of inner and outer unit cells with burnup
WEIGHT FACTORS FOR ORIGEN-S: THERM, RES, FAST

Origen requires data for all significant nuclide transition rates, by isotopic decay or neutron absorption. Isotopic decay rates are constant. While neutron reaction rates may vary with time, the Origen model requires that a constant or effective reaction rate be used during the period for which the library is applied. Origen uses the convention of normalizing cross sections to thermal flux and requiring thermal flux, or power to be input. The following may be used when neutron flux spectrum is available and with the assumption that thermal reaction rates follow that of a 1/v absorber.

The groups 1 to n include the thermal groups (below 0.5 eV) and $E_i$ is derived by some logical method for representing the energy of each group. THERM corresponds to the spectrum-averaged cross section in the thermal energy range.

$$THERM = 0.15906^\sum_{i=1}^{n} \frac{A_i}{\sum_{i=1}^{n} E_i}$$

RES is defined in the epithermal energy range (0.5 eV to 1 MeV) as follows:

$$RES = \frac{1}{MEV/ E_i) \sum_{i=1}^{m} \frac{A_i}{A_i} = 0.06892^\sum_{i=1}^{m} A_i$$

Where the groups from 1 to m are the epithermal energy range and $E_1$ and $E_2$ are 0.5 eV and 1 MeV respectively.
FAST is defined as 1.45 times the ratio of the flux above 1 MeV to the thermal flux.

$$FAST = 1.45^{\delta_{i=1}^{k} M_i}$$

CONCLUSION

This study demonstrates the preliminary results of the neutronic and burnup calculations of a pebble bed reactor THTR via SCALE4.4 code, KENOVa and ORIGEN-S modules. The BOC reactivities and the integrated group fluxes of radially two-zone core are evaluated by the use of KENOVa module. The changes in the fissile contents of the core and reactivity calculations are performed by ORIGEN-S module.

REFERENCES


