Study for ^{228}Th reduction in thermal reactor with Th-U fuel cycls

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Abstract By using computer code WIMS/CENDL, the effects of some parameters, core configuration such as fuel element structure, neutron flux and burn-up, are discussed in this paper. It is shown that high neutron flux, small fuel rod diameter, large volume ratio of coolant to fuel, seed-blank heterogeneous core arrangement and ^{231}Pa chemical separation are necessary for reducing ^{228}Th production in reactor.
Keywords ^{228}Th, Th-U fuel cycle, Thermal reactor

1 Introduction

Energy resource is an essential prerequisite to realize strategic objectives of the national economic development in China. According to the prediction, by the middle of the next century, nuclear power is expected to be more than 20% of the total electricity generation, about 240 GW.[1] If these nuclear power were generated by PWR, the total natural uranium resoures consumption would be about 27000~33000 t per year.

Because of the limitation of uranium resources in China, it is very attractive to develop thermal breeders. Thermal breeders have advantages of low fissile material inventory, nuclear fuel flexibility and much more operation experience.It is a practical pathway to expand nuclear power with limited uranium resources.

Thorium is an abundant nuclear resources, at least three times as abundant in the earth's surface as uranium. Thorium can be used in thermal reactor in high conversion ratio, even to realize self-consistent or breeding.[2] On the other hand, thorium generates less minor actinides and plutonium in reactor, it is clean and nuclear proliferation resistant compared with the reactors loaded with uranium.[3]

One of the main concerned issues for thorium fuel cycle is the generation of harmful nuclide, ^{228}Th. It is mainly generated by decay of its mother nuclide, ^{232}U. ^{228}Th will decay quickly and produce some gamma emitters with high energy, such as ^{208}Tl and ^{212}Bi. These nuclides are much troublesome in spent fuel reprocessing and fuel fabrication because of its strong radioactivity. ^{228}Th inventory in reactor core is dependent on many parameters, such as neutron spectrum, flux level and core structure, study on its production and depletion procedure is an important task. Some results are briefly discussed in this paper.

2 Basic theory

The burn-up chain for ^{228}Th can be shown as Fig.1.

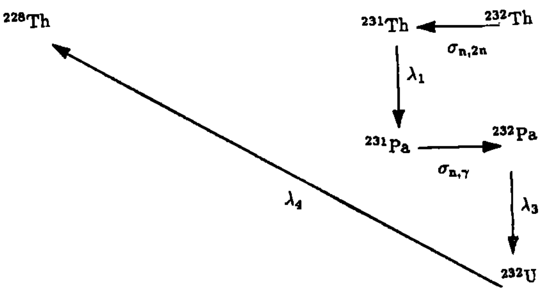

Fig.1 The burn-up chain from ^{232}Th to ^{288}Th

The ^{232}Th (n,2n) reaction is a main pathway for ^{228}Th production, the reaction rate f_0 can be written as:

$$f_0 = \int\int N_0 \sigma_{n,2n}(E,r)\phi(E,r)dEdV$$

For a homogeneous reactor, we have:

$$f_0 = N_0 \overline{\sigma}_{n,2n} \overline{\Phi}$$
$$= \Big(\frac{\sigma_{n,2n}}{\sigma_f}\Big)\Big(\frac{N_0 \sigma_f \Phi}{R_0}\Big)R_0$$

This work is Supported by National Natural Science Foundation in China
Manuscript received date: 1998-09-03

$$= \beta \times f_1 \times R_0$$

Here, N_0 is the quantity of ^{232}Th, $\sigma_{n,2n}$ and σ_f are the cross section of (n,2n) and (n,f) reaction in fast neutron energy (E >6 MeV), respectively. R_0 is the total fission rate (n/s.), f_1 the ratio of fission reaction of ^{232}Th to ^{233}U, β reaction ratio of (n,2n) to fission for ^{232}Th, β is a constant, R_0 is dependent on reactor thermal power, f_1 can be calculated in WIMSD4[4] with the help of reaction edit option.

If $N_i(i{=}1,2,\cdots,5)$ is the inventory of ^{231}Th, ^{231}Pa, ^{232}Pa, ^{232}U and ^{228}Th, respectively, we have

$$\frac{dN_1}{dt} = f_0 - (\lambda_1 + \sigma_{a.1}\Phi)N_1$$

$$\frac{dN_2}{dt} = \lambda_1 N_1 - (\lambda_2 + \sigma_{a.2}\Phi)N_2$$

$$\frac{dN_3}{dt} = \sigma_{\gamma,2}\Phi N_2 - (\lambda_3 + \sigma_{a.3}\Phi)N_3$$

$$\frac{dN_4}{dt} = \lambda_3 N_3 - (\lambda_4 + \sigma_{a.4}\Phi)N_4$$

$$\frac{dN_5}{dt} = \lambda_4 N_4 - (\lambda_5 + \sigma_{a.5}\Phi)N_5$$

Suppose that neutron flux is a constant, then the equilibrium inventory for these nuclides are calculated.

3 ^{228}Th inventory

Let us consider a thermal lattice with ThO_2 fuel and D_2O coolant and analyse the effect of ^{232}Th inventory in different condition.

3.1 Fuel radius and V_m/V_f

Large V_m/V_f and small fuel rod radius can slow down fast neutron effectively, hence reduce fast neutron flux and (n,2n) reaction rate of ^{232}Th. Calculation results are given in Fig.2,

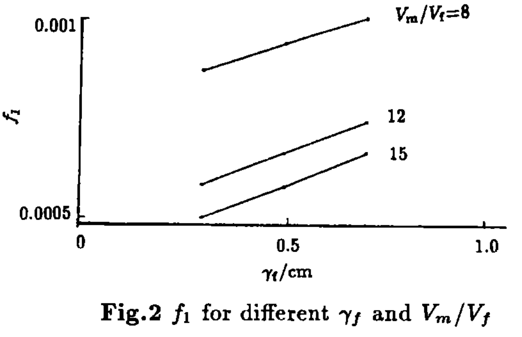

Fig.2 f_1 for different γ_f and V_m/V_f

it is shown that large V_m/V_f and small fuel rod radius can reduce the production of ^{228}Th.

3.2 Neutron flux

In burn-up chain, disappearance of a nuclide is completed in two ways, decay or neutron absorption. Neutron flux can change this procedure, high flux is helpful for ^{232}U to absorb neutron, then decrease the fraction of ^{232}U to decay to ^{228}Th more effectively, and reduce daughter product, the nuclide inventory in different neutron flux is given in Fig.3.

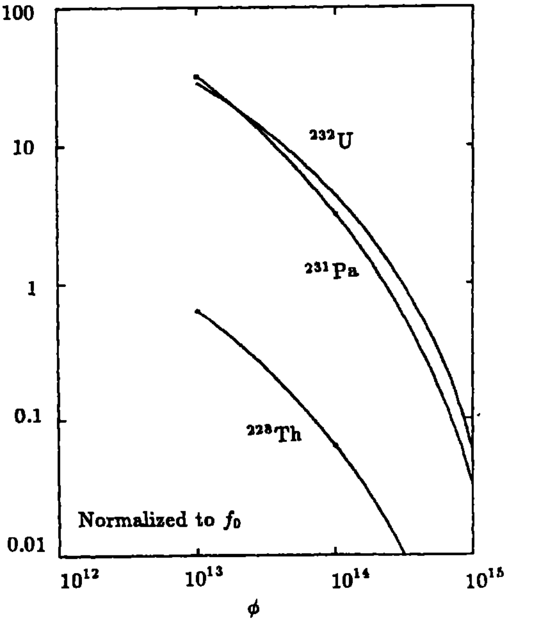

Fig.3 ^{231}Pa, ^{232}U and ^{228}Th inventory as function of neutron flux

3.3 Other parameters analysis

^{231}Pa is an intermediate nuclide from ^{232}Th to ^{228}Th, in low neutron flux, because of its accumulation, chemical separation of ^{231}Pa will reduce ^{228}Th inventory.

In seed-blank heterageneous core, fission and breeding are completed in two different regions, this technique can reduce (n,2n) reaction of ^{232}Th very effectively. This characteristic depends on concrete core structure and burn-up, detailed analysis is not included in the paper.

4 Conclusion and discussion

Based on prior calculation and analysis, it is shown that high neutron flux, small fuel rod diameter, large volume ratio of coolant to fuel, ^{231}Pa separation and seed-blank heterogeneous core are helpful to reduce the production of ^{228}Th. In which the neutron flux level is the most important factor.

Acknowledgement

The author is greatly indebed to Profs. DING Dazhao, LUO Zhangling, ZHAO Zhixiang, SHI Yongqian, LIU Guisheng for their helpful suggession and discussion in the work.

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