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摘　要

从理论分析和运行结果比较了高通量工程试验堆（HFETR）80 盒、60 盒燃料元件堆芯的性能。结果表明，HFETR 80 盒元件堆芯在允许功率、材料辐照和单晶硅掺杂、钼-锝同位素生产等方面与 60 盒元件堆芯性能相同。80 盒元件堆芯更有利于 500 kW 试验回路入堆后堆的运行，有利于大幅度提高高比度^{60}Co 医疗源产量和元件利用率。和 60 盒元件堆芯实际生产情况相比，HFETR 80 盒元件堆芯每年的^{60}Co 同位素效益增加 380 万元以上。

The Study on 80 Fuel Assemblies Core for HFETR

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ABSTRACT

The performance of 80 and 60 fuel assemblies cores for High Flux Engineering Test Reactor (HFETR) has been compared by theoretical analysis and operating results. These results show that the core performance of 80 fuel assemblies is the same as that of 60 fuel assemblies in the following aspects: the permission power of core, the irradiation test of materials, the transmutation doping of single crystalling silicon, the production of Mo-Tc isotopes, etc. The core of 80 fuel assemblies is more convenient in operation after 500 kW test loop installed, and in greatly raising the production of ^{60}Co source with high specific radioactivity and the usage of fuel. As compared to the production of ^{60}Co source of 60 fuel assemblies core, the benefit of 80 fuel assemblies core can increase more than 3.8 millions yuan per year.

INTRODUCTION

The main task for High Flux Engineering Test Reactor (HFETR) is to carry out irradiation test of power reactor fuel assembly and nuclear materials, and to give consideration to the production of radioactive isotopes, etc. To carry out conveniently above tasks, a few studies have been done. The numbers of core fuel assemblies of HFETR have been increased from 25 to 60. To further raise the economic benefits and social benefits of HFETR, to further deep and careful study concerning about its loading has been done in the work.

Now, the two main ways to greatly raise the economic benefits may be adapted: one is to greatly raise the production of ^{60}Co medical source with high specific radioactivity (the sale price of ^{60}Co medical source with high specific radioactivity is 5 times that of ^{60}Co industry source with low specific radioactivity, however both the neutron fluence needed is same), the other is to greatly improve the usage of fuel. The former asks to increase the numbers of the big cobalt targets in the region of fuel assembly, the later asks to all the discharge burnup is very approximate to the burnup limit (45%). To increase the numbers of the big cobalt targets in the region of fuel assembly and let the core time be enough, the fuel assembly loading must be enlarged; to all the discharge burnup is very approximate to the burnup limit, the batch numbers of refuelling must be increased, the fuel assembly loading must be enlarged too.

After detail and careful study, we came to a conclusion: under no changing the equipment and system, through varying the numbers of the fuel assembly of HFETR from 60 to 80, the operating benefit will be greatly raised.

1 THE CORE LOADING DESIGN

The arrangement of fuel assembly is satisfied with the symmetric principle, 20 fresh fuel assemblies are loaded every cycle. The low leakage loading scheme is adapted, the equilibrium refuelling scheme is carried out. The material irradiation will be ensured too.

Under ensuring the core time, the theoretical analysis and operating results show: only 3 big cobalt targets can be arranged in the fuel region of 60 fuel assembly core, while 5 big cobalt targets can be arranged in the fuel region of 80 fuel assembly core. To efficiently use neutron and keep the continuity of ^{60}Co radioactive istopes production, suitable number of big cobalt targets may be arranged in the first layer beryllium reflector, a ring of big cobalt targets may be arranged in the second layer beryllium reflector, the small cobalt targets may be arranged in all beryllium centralholes.

2 THE CORE THEORETICAL ANALYSIS AND OPERATION RESULTS

The code " Few Group Two Dimension Diffusion and Burnup Code" has been adapted in the physics computation of HFETR. The operation results of HFETR have shown that the computation results of the code concerning about effective neutron multiplication factor and neutron fluence and so on are available.

2.1 The ^{60}Co isotopes Production of HFETR

Detail study has shown that the better irradiation course to produce ^{60}Co isotope medical source with high specific radioactivity is: to move the large cobalt with 370 GBq/g in the outer second ring beryllium reflector of the core into inner first ring beryllium reflector of the core, to move the large cobalt with 1110 GBq/g into the fuel assembly region, and to withdraw out the large cobalt with 3330 GBq/g from the core.

The ^{60}Co isotope production of HFETR per cycle is given in table one.

Table 1 HFETR ^{60}Co isotope production per cycle (GBq)

number of the core fuel assembly	big cobalt		Small cobalt	Control rod cobalt	Total production	Notes
	Region of fuel assembly	Total production				
60	183	586	113	279	978	without 500 kW test loop
80	282	686	91.3	226	1003	
80	278	667	85.8	224	976	with test loop

We may see the following conclusion from the data in Table 1: the total production of ^{60}Co isotope of three type core is nearly the same, the ^{60}Co isotope production in the fuel assemly region of 80 fuel assembles core is more than that of 60 fuel assembles core. Without 500 kW test loop, the production of ^{60}Co isotope with high specific radioactivity of 80 fuel assemblies core is more than 53% that of 60 fuel assemblies core; with 500 kW test loop, the former' s production is more than 52% that of the latter.

According to the sale price of ^{60}Co isotope source in present market, we may count out the cost of ^{60}Co isotope source. The results show that the benefits of ^{60}Co

isotope source of 80 fuel assemblies core is more than 3.8 millions yuan that of 60 fuel assemblies core per year.

2.2 HFETR Core Neutron Irradiation Capacity

There are two Φ 180 and two Φ 120 and four Φ 63 irradiation channels in HFETR core. The central holes (Φ 12) in fuel assembly may be used in material irradiation. These channel's Irradiation Capacity is an important parameter in the assessment of the core performances.

(1) The Transmutation Doping of Single Crystalling Silicon The transmutation doping of single crystalling silicon of HFETR is often carried out in two Φ 180 channels. The thermal neutron fluence by measurment shows that the capacity of transmutation doping of single crystalling silicon of 80-fuel-assembly core is the same as that of 60-fuel-assembly core.

(2) A-508 Ⅲ Steel Irradiation The irradiation sample of the nuclear power plant pressure vessel steel (A-508 Ⅲ steel) is often tested in Φ 120 channels. Three irradiated fuel assemblies are arranged beside Φ 120 channel in 60 fuel assembly core, the fast neutron flux ($E \geqslant 1$MeV) obtained by measuring is 1.2×10^{13}n/cm^2 · s); five irradiated fuel assemblies are arranged beside Φ 120 channel in 80 fuel assembly core, the fast neutron flux ($E \geqslant 1$MeV) obtained by measuring is 1.44×10^{13}n/ (cm^2 · s). Therefore the irradiation capacity in the two cores to A-508 Ⅲ steel is nearly the same.

(3) Mo-Tc Isotopes Production HFETR Mo-Tc isotopes production is often carried out in Φ 63 channels. Both theoretical computation and measurment have shown that the Mo-Tc isotopes production capacity of 80 fuel assemblies core is the same as that of 60 fuel assemblies core.

(4) Irradiation Capacity in the Central Holes of Fuel Assemblies The middle life isotopes production is often carried out in the central hole of fuel assembly. The simple theoretical analysis and computation have shown that the total irradiation capacity in the central holes of fuel assemblies has no relation with the numbers of fuel assemblies in HFETR core.

(5) Pressure Vessel Irradiation Effect HFETR's reactor life is mainly decided by its pressure vessel' s time. We know from the fast neutron flux in the Φ 120 channels that HFETR pressure vessel irradiation effect of 80 fuel assemblies core is nearly the same with that of 60 fuel assemblies core.

2.3 HFETR Fuel Assembly Usage analysis

Fuel assembly cost is a large fraction in the cost of nuclear reactor operation cost. It has an important economic meaning for HFETR through core fuel management to save fuel assemblies. Theoretical analysis shows that the fuel assembly usage of the the four region lodaing of 80 fuel assemblies core can save by ten percent as compared with that of the three region loading of 60 fuel assemblies core.

2.4 Thermal Performance Analysis

2.4.1 Theoretic Analysis of HFETR Permission Power

The limit factor of HFETR premission power is: the maximum surface heat flux of fuel cladding is smaller than its critcal heat flux, the maximum surface temperature of fuel cladding is lower than the water saturation temperature, fuel assembly minimum burnout ratio can' t be smaller than 1.95.

There are three primary pumps in the core under 60 and 80 fuel assemblies core operation, the total water flow of HFETR core is 3640 t/h and 3850 t/h respectively, internal water flow velocity in fuel assembly is 6.23 m/s and 5.46 m/s respectively.

We may assume that the fuel assembly' s permission power is in direct proportion to the water flow velocity in the fuel assembly (this assumption trends to safety when the water velocity slow down). Then, we know from the physical computation results that HFETR 80 fuel assemblies core is advantageous to raise its permission power.

2.4.2 HFETR Core Operation Results

The data in Table 2 are obtained by HFETR operating. Where, *Kr* is the ratio of the hot fuel assembly' s power to the average power of core fuel assemblies. The core operation power is 50 mW, the six fuel asemblies in Table 2 is hot fuel assemblies obtained by physical computation.

Table 2 HFETR operation results

Cycle	33- I		34- I		35- I		36- I		
Location	*Kr*	*P*/kW	*Kr*	*P*/kW	*Kr*	*P*/kW	Location	*Kr*	*P*/kW
L11	1.558	1256	1.957	1223	1.670	1044	L14	1.680	1050
H10	1.221	985	1.478	924	1.326	829	I12	1.934	1209
N12	1.202	969	1.419	887	1.276	798	N13	1.521	951
K12	1.102	889	1.240	775	1.178	736	K12	1.774	1109
J10	1.538	1240	1.797	1123	1.637	1023	K13	1.770	1106
J12	0.847	683	1.411	882	1.250	781	J13	2.069	1293

We may see some conclusions in Table 2:

(1) The theoretic analytic results to 80 fuel assemblies core are correct.

(2) Acorrding to the power of 6 fuel assemblies with measuring temperature equipment, the radial power tilt factor of 80 fuel assemblies core is little more than that of 60 fuel assemblies core.

(3) With 500 kW test loop, the core radial power tilt factor become larger due to the core loading with asymmetry.

(4) The hot fuel assembly power of 80 fuel assemblies core is nearly the same with that of 60 fuel assemblies core, therefore HFETR is safe.

We can reach a conclusion according to above results: by using the same equipment and system, 80 fuel assemblies are loaded in HFETR core, the core thermal performances are safe, the economic benefit is obvious, the neutron irradiation capacity of 80 fuel assemblies is the same with that of 60 fuel assemblies core, the 80 fuel assemblies core is advantageous to raise the core permission power and to raise fuel usage and to irradiate 500 kW test loop, it is advantageous to greatly improve the production of ^{60}Co source with high specific radio activity too. The economic benefit of 80 fuel assemblies core is more than 3.8 millions yuan compared to the that of 60 fuel assemblies core per year.

3 DISCUSSION

(1) With 500 kW test loop, HFETR core reactivity would decrease by $5\beta_{eff}$. There are not enough core time in the core of 60 fuel assemblies, therefore we must operate the core of 80 fuel assemblies.

(2) Under ensuring 500 kW test loop irradiation. If the beryllium assemblies in the centre of HFETR core are withdrawnd by step and the fuel asemblies are arranged more far away from 500 kW test loop, it is advantageous to raise the production of ^{60}Co source with high specific radio activity.

(3) If the 8 outer control rods are replaced by the big cobalt targets, it will be advantageous to raise the production of ^{60}Co source with high specific radio activity.

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