PROBLEMS CONCERNED IN FUEL DESIGN OF CARR

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Abstract

For a multipurpose research rector with rather high performance like CARR, to lower the fuel meat temperature, to control the oxide layer growth and to ensure the structural stability of fuel assembly are the main problems to be solved in the fuel design and briefly described in this paper.

INTRODUCTION

The existing two research reactors in China Institute of Atomic Energy (CIAE), Heavy Water Research Reactor (HWRR) and Swimming Pool Reactor (SPR) were built, respectively, in 1958 and 1964 and now still in operation. Although some modification and reconstruction work and recently the renovation job for these two reactors were performed, they are both in extended service and facing the aging problem. It is expected that they will be out of service at about 2000. So, China has planned to design and build a new research reactor at CIAE.

In consideration of the need of increasing requirements in science and technology applications, the scheduled research reactor should be one with higher preformance than the existing two old reactors in order to match the R & D tasks related to the coming 21st century, such as high enough neutron flux available for the neutron scattering experiments, updated engineered safety features for research reactors, etc.

The scheduled reactor is named China Advanced Research Reactor (CARR), having finished the feasibility study and got the approval from National Planning Committee, we now enter the preliminary design phase of the project. CARR is a 60 MW tank-in-pool and inverse neutron trap type research reactor with a compact core structure, light water as the coolant and heavy water as the outer reflector. The maximum unperturbed thermal neutron flux in the reflector will be not less than $8 \cdot 10^{14}$n/cm^2/sec. In order to improve the thermal-hydraulic condition of CARR's fuel assembly, based on the optimization work, now we adopt the following parameters for the CARR fuel design as listed in table 1.

Table 1. Main Features of CARR

Item	Unit	Value
Reactor Power	MW	60
Core Height(active)	cm	85.0
Coolant		H_20
Fuel Meat		U_3Si_2-Al
^{235}U Enrichment	%	20
Uranium Density	g/cm^3	4.3
^{235}U Loading	kg	11.1
Fuel Assembly Size	mm× mm	76.2× 76.2
Number of Plates	Pieces	21
^{235}U content in each Assembly	g	567.4
Width of Fuel plate	mm	71
Length of Fuel Plate	mm	880
Thickness of Fuel Plate	mm	1.36
Meat Length	mm	850
Meat Width	mm	61.6
Meat Thickness	mm	0.6
Cladding Material		Al Alloy
Cladding Thickness	mm	0.38
Gap between Plates	mm	2.59× 2, 2.45× 2, 2.32× 2, 2.2× 14

CONSIDERATIONS IN FUEL DESIGN

The concept of inverse neutron trap with a compact core structure will bring great favor to the neutron scattering experiments user. But, on the other hand, because of CARR's multipurpose aim, we have to give considerations to requirements of various users when making the design. For example, it must take accounts of enough irradiation space for radioisotope production and for fuel and material tests, of enough excess reactivity, and of not too short of reactor operation cycle, As a result, the reactor power has to be raised properly, a sufficient ^{235}U-loading of the core should be required and high density uranium fuel has to be used. Due to the high core power density which leads to rather high heat flux density, the coolant velocity has to be increased. This will render higher requirements to fuel design.

U_3Si_2-Al dispersion fuel is adopted in CARR fuel design. It possesses the merit properties as follows:

(1) quite high uranium density in fuel meat

(2) good compatibility of U_3Si_2 with aluminum and coolant

(3) very good heat conductivity, similar to that of UAl_x and U_3O_8 dispersion fuel

(4) excellent blister resistance threshold (higher than 515?)

(5) stable swelling behavior under irradiation, basically the same swelling rate under irradiation as that of UAl_x

(6) high performance of fission gas retaining and low release of volatile fission product.

The aluminum alloy is adopted as cladding material. It possesses good properties of heat conductivity, small cross-section of neutron absorption, good compatibility with meat U_3Si_2-Al and low cost. However, the relative low strength and the limitation of operation temperature for restraining the corrosion and temperature rising caused by oxide layer at the EOC have to be taken into accounts in the fuel design.

As for the fuel assembly structure, three options could be chosen: involute-shaped plate type, curved plate type and plain plate type. The involute-shaped fuel plate possesses the most perfect performance for neutron beam reactor because the fraction of structural material of such fuel is reduced to the least, so it makes the reactor core very compact. In addition, this kind fuel possesses quite good structural stability and high critical coolant velocity. However, because one single fuel assembly itself consists of an integrated core, it is difficult to be equipped with any additional experimental channels in the core to meet the requirement of material irradiation tests. And further more, the burnup of the unloading fuel will be shallow because the refueling is just in one complete piece outing. Besides, the fabrication of such fuel assembly needs skill technique which China is lack of at present. Similarly, the curved plate assembly also presents the difficulties in fabricating and in control rods lay-out in the core. In contrast, with plain plate assemblies, besides the ripe experience has already got in China in designing, fabricating and putting into operation of such kind of fuel assemblies, the reactor core will possess relative flexible lay out. So, the MTR type fuel assembly with plain plate has been decided to be adopted in the design of CARR. The data are listed in table 1.

KEY PROBLEMS TO BE SOLVED

Since the high heat flux and high coolant velocity, the running condition of CARR fuel is quite harsh. Table 2 lists some of its thermal-hydraulic parameters.

Table 2. Some Parameters of CARR Fuel

Maximum Surface Temperature	142?
Maximum Meat Temperature at BOC	160?
Average Heat Flux	1.7 MW/m^2
Maximum Heat Flux	3.67 MW/m^2
Residence Time in Core(Full Power Days)	60 days
Peak Fission Density	0.7×10^{21} f $/cm^3$
Coolant Flowrate	2450 m^3/hr
Coolant Velocity	10 m/s
Inlet Pressure	0.92 MPa
Inlet Temperature	35?
Outlet Tempperature	55?

Led by Argonne National Laboratory (ANL) in the United States, the international program, Reduced Enrichment in Research and Test Reactors, has made great efforts in extensive research and development work to low-enriched uranium silicide-aluminum dispersion plate-type fuels. According to the results obtained from irradiation tests on fuel elements, performed at the Oak Ridge Research Reactor, the document NUREG 1313 declared[1]:

Typical maximum power developed in a test fuel element was approximately 1 MW, leading to about 1.4 MW/m^2 heat flux and a maximum fuel-meat temperature of approximately 130? . These parameters determine the upper limits for the range of conditions actually tested and, therefore, define the upper limits for the range over which the conclusions of the reports apply. However, there appear to be no tested parameters of these fuels that are strongly correlated to power level or power density, so extrapolation of the conclusions to higher ranges is not ruled out .

Coincidentally, the peak temperatures in fuel meat at BOC in research reactors FRM-II (LEU design, ANL made), JMTR (LEU fuel) and OSIRIS are respectively, 130? ,125? and 105? [2] In comparison, this value of CARR design is rather high.

The experimental study stated[3], high meat temperature under irradiation condition for high uranium density fuel may result in a potential problem of swelling due to the formation of the $U(AlSi)_3$ interdiffusion between U_3Si_2 and aluminum. The interdiffusion process may consumed all matrix aluminum at EOC of fuel irradiation and the fuel may exhibit to reach a breakaway swelling stage in which fission gas bubbles interlink and grow to rather large size.

Just worrying about the features aforementioned, we have made our efforts to improve the thermal-hydraulic condition of CARR fuel. The peak fuel meat temperature designed was reduced from 194? to 160? at BOC and the correspondent uranium density lowered from

4.6g/cm^3 to 4.3g/cm^3 . This temperature still seems to be high and we have to adopt some measures to restrain the temperature rising due to formation of oxide layer at EOC.

The second problem being concerned is the temperature rising due to oxide layer on fuel cladding. Because the heat conductivity of the oxide corrosion product is only 1% of that of aluminum, it makes the thermal condition seriously reduced. The higher the fuel plate heat flux, the higher the temperature rising caused.

The temperature rising is proportional to the product of heat flux and the thickness of oxide layer. The following criteria should be adhered to for controlling the growing of oxide layer.

——No peeling off of the oxide layer.

——No impact on the structural stability for fuel assemblies due to temperature rising of oxide layer.

——The temperature rising of fuel meat below the limit value.

To select an adequate cladding material with quite good mechanical and low-corrosion performance under rather high temperature and harsh hydraulic condition is virtually important. At present, there are no domestic data of oxide layer growing of aluminum alloy under heat flux condition. Meanwhile, the data of such kind from abroad are got from quite different testing conditions from that of CARR. The mechanism of oxide layer growth is very complicated and closely related to many factors, such as cladding surface temperature, heat flux, water chemistry, water temperature, coolant velocity, the ratio of total surface of aluminum to water volume, and the purification rate while operation, etc. So, we have to devote our efforts to seeking a qualified aluminum alloy and a good water chemistry environment in order to avoid the temperatures of fuel meat and cladding surface not too high at EOC.

The third problem concerned is the structural stability of fuel assembly. This problem is of vital importance to ensuring of fuel heat removing during normal operation condition and with no hindering of reactor shut down and ensuring effective cooling down of reactor core after accident. The main aspects causing the fuel assemblies in structural unsuitability are: high velocity of the coolant, its uneven distribution and heat stress. The critical velocity of CARR standard fuel assembly, upon calculation, is 16m/s and that designed is 10m/s.

The structure of fuel assembly will affect the flowrate distribution a lot. It is commonly believed that coolant velocity through gap channels with equal thickness is identical. However, because of the reduced size end of the fuel assembly lower plug, the water flow through identical gaps is uneven. For the outer part of a fuel assembly, water flowrate is relatively low. In CARR design, rectangle plug with reduced size is adopted. The plug dimension is made as large as possible. Meanwhile, properly widen the outer gap channels so as to make the flowrate distribution of whole assembly even. In this way, the condition of force subjected and stress to the fuel assembly is expected to be improved and the structural stability enhanced.

In addition, other measures will be taken to enhance the stability, for example, location-fixed combs are set at both ends of fuel assembly, manufacturing allowance is strictly controlled when fabricating the gaps width, and so on.

To counter the weakness of plain plate type fuel assembly, appropriate aluminum alloy with relatively high strength has to be selected as fuel cladding and structure material. And further more, the operation temperature is required as low as possible for holding its rather high strength.

The new reactor CARR to be built in CIAE is a rather high performance research reactor facing the 21st century. Now, the CARR project has begun its preliminary design phase which will last for one and half years. It will be put into operation in 2004. We hope that the problems mentioned above in this paper will be solved through cooperation with experts from countries.

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