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YBS, the Critical Assembly for ADS Experimental Research in CIAE

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1. Introduction

ADS is short for Accelerator Driven Subcritical system with the ability of transmutation long life radioactive waste, breeding fission nuclides and produce energy. First ADS research group was found in 1995 in China Institute of Atomic Energy and has made some progress so far. CIAE started to construct the YBS criticality assembly in 2012 with the cooperation of Chinese Academy of Sciences in order to focusing on subjects below:

- Benchmark experiments for codes and nuclear data validations.
- Research of reactivity monitoring methods of ADS subcritical reactor, such as source multiplication, source jerk, pulsed source and noised analysis.
- Measurement of reactivity worth for important structure materials.
- Education and training for researchers and operators.

The name YBS stands for the Chinese name You Bang Shan which means the core structure is uranium rod lattice. It is known that the measurement of reactivity coefficient can be much more accurate and reliable when the assembly is around critical, so the YBS assembly is designed to be a critical assembly. Full measurements of reactivity coefficients will be carried out in critical experiments in earlier stage, then the YBS assembly will run at certain and credible subcritical status, which can definitely improve the quality of experiments results. The installation of the YBS assembly is undergoing and it will reach to critical in the middle of 2016.

2. Physical Design of the YBS Assembly (Lead Core)

The YBS assembly consists of two types of cores, one is water core and the other is lead core. In this paper the lead core will be discussed.

2.1 Main consideration of Lead core

The following issues have be considered in physics design:

- Lead (Pb) is the common material as the coolant, so it should be considered in the YBS critical assembly.
- Target zone in the center of the assembly should be considered as the unique part of ADS, different from regular critical assembly.
- Fast neutron spectrum.
- Critical.
- Safety Control.

The first three demands make it very hard for the later one, critical. In order to solve this problem, increasing the amount of fuel, applying effective reflector and introduce thermal fission zone outside the experimental zone are employed. The physics design was done in 2014 by UK Monte Carlo code MONK 9A with nuclear data ENDF/B-VI.

2.2 Fuel rods and arrangement

The YBS assembly (Lead Core) uses two kinds of fuel rods. One is 20% enrichment U_3O_8 powder with Zr clad with the number of 945, and the other is 90% enrichment metal U with stainless steel clad with the number of 101. Both of the fuel rods have 400mm length of fission materials and top/bottom reflector pellets to reduce neutron leakage.

The fuel arrangement of YBS lead core is four rings of 90% fuel rods surround the target zone in the center, and eight rings of 20% fuel rods surround outside. They are all filled into lead body in concentric cycles with the out diameter 445mm. While in the outside space, part of 20% enrichment rods are filled into the polyethylene and reflected by enough polyethylene and graphite (800mm thickness). These 380 rods are arranged in concentric pattern with best pitch which can add 0.17delta k/k reactivity so that the aim of criticality can be achieved. See Fig. 1 below.

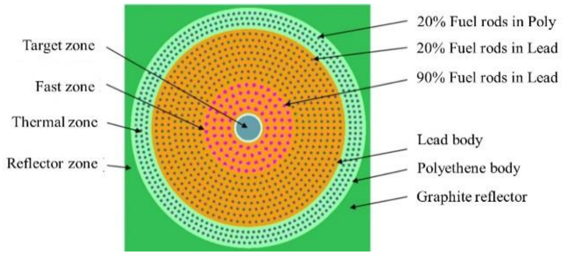

Fig. 1. Intersecting view of fuel rod arrangement in YBS lead core.

2.3 Reflector system

The leakage is the main difficulty for critical. The fast spectrum and target zone in the center make it worse to maintain neutron balance. Thus the reflector system is very important to the critical assembly. YBS lead core equips a complex and effective reflector system to reduce the neutron leakage, meanwhile slow down the neutrons as little as possible in fast zone.

Many operations are in the top of the assembly, so the top reflector should not be too large. The 195mm Beryllium metal is above the 90% fuel rods zone to avoid too much slowdown and 195mm polyethylene is above the 20% fuel rods zone around the middle Be.

The bottom and side reflector are graphite with the density of 1.87g/cm^3 and <1ppm B concentration. Graphite doesn't absorb too many neutrons and is good reflector with large scale. In the bottom the thickness is 300mm and in the side is 800mm. Fig. 2 presents the profile view.

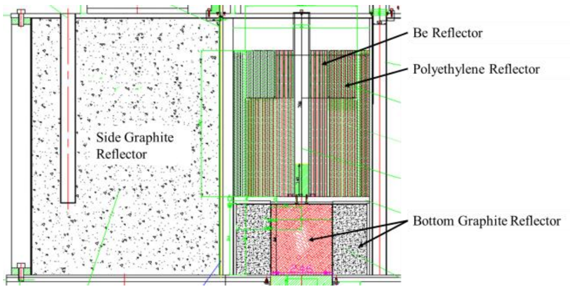

Fig. 2. Reflector system of YBS lead core.

2.4 Target zone

Target zone is used for position neutron sources, structure materials and target materials in order to simulate the coupling effect of target and reactor. The target zone is made of stainless steel with outside diameter 65mm, inner diameter 55mm and 640mm height, filling in the center of lead body, see Fig. 3 below.

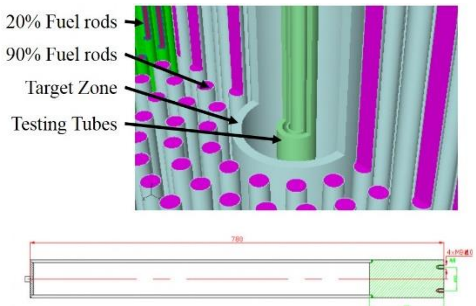

Fig. 3. Target zone of YBS lead core.

2.5 Safety control system

The safety control system of YBS lead core consists of control rods and movable bottom graphite block.

The control rods of YBS lead core consists of two safety rods with the worth of 1%Δk/k and two adjust rods with the worth of 0.2%Δk/k, all are placed symmetrically in the tubes in the graphite reflector to save rooms for fuel rods which can increase the fission materials and reduce the leakage of neutrons when they are pull out. Safety rod uses B_4C as the absorber. Adjust rod uses Cd as the absorber. The distribution of control rods can be found in Fig. 4.

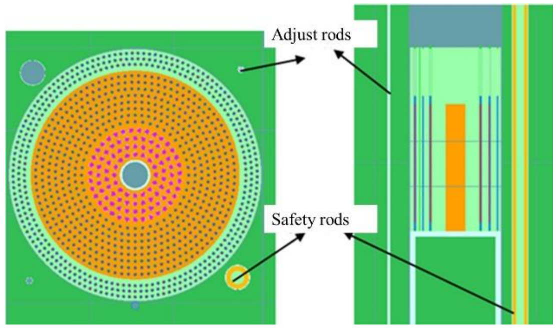

Fig. 4. Control rods distribution of YBS lead core.

The movable bottom graphite block is placed in the middle of bottom reflector with the worth of 1.1%Δk/k. In normal conditions, it works as a part of reflector and will drop out by gravity in less than 1 second when any abnormal event happened, see Fig. 5 below.

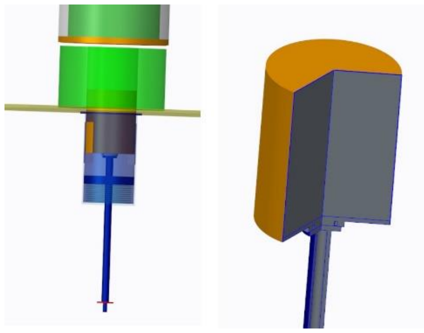

Fig. 5. Movable bottom graphite block of YBS lead core.

3. Theoretical Calculation Results

Fully theoretical calculation was done in 2014 to understand loading patterns, neutron spectrum, neutron flux distribution, reactivity co-efficient and control rod worth, by MONK with ENDF/B-VI data library.

YBS lead core will reach to the critical by increasing the number of fuel rods in the last rings in polyethylene. With the full loading the k-effective will be 1.02450±0.00008, and worth of one fuel rod is 57.8PCM. The critical loading number is 1002, see the Fig. 6 below.

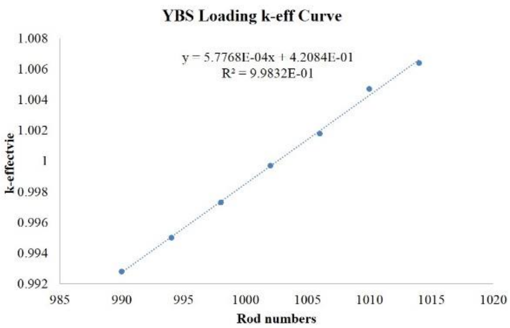

Fig. 6. Loading Curve of k-effective.

The demand of critical is satisfied with more than 2% margin and the worth of single rod is suitable for experiment operations.

With the fission source the neutron flux distribution and spectrum are calculated, see Fig. 7 and Fig. 8 below.

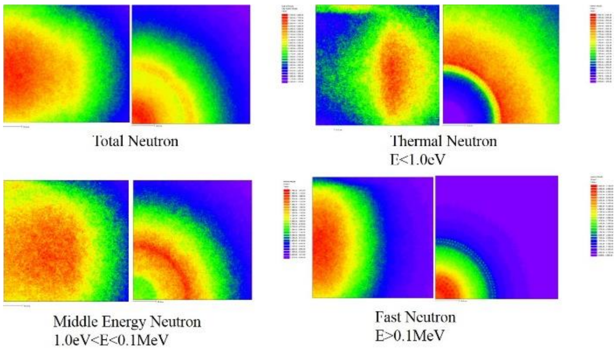

Fig. 7. Neutron distributions with different energy.

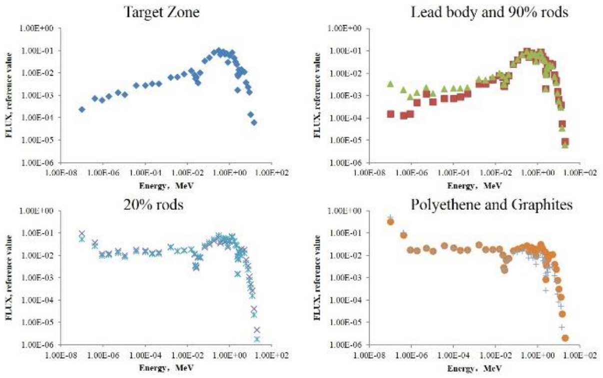

Fig. 8. Neutron spectrum in different place.

In the fast zone, the neutron spectrum is close to the fission spectrum with little thermal neutrons, the demand of neutron energy is satisfied and it can be used to simulate the ADS for experimental research.

4. Current Status

Right now the main work are done of the assembly. The manufacture of fuel rods, reflectors, lead body, target zone, operation platform are finished. The reactor hall, radiation protection, control and protect system and control room are ready for experiments. Commission and debug are the focus work in later 2015. See the Fig. 9 and Fig. 10.

Fig. 9. Main part of YBS lead core.

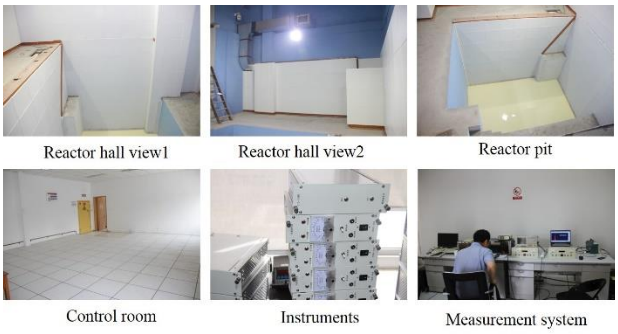

Fig. 10. Reactor hall and other part of YBS.

5. Conclusion

In order to carry out more intensive experimental research on ADS field, CIAE began the design and construction of the YBS criticality assembly in 2012. It uses high enrichment uranium-235 as fuel and the lead as the structure material, will be the first critical assembly in China as the experimental facility of the engineering model of ADS. The fast neutron spectrum, target zone in the center of the lead body, certain and credible subcritical status by accurate measurement of reactivity coefficients make it the benchmark assembly for experimental research and theoretical validations. The installation of the assembly body is undergoing and it will reach to critical in the middle of 2016.

References

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