ON POWER REFUELING MANAGEMENT OF HTR-PM

Sun Furui, Luo Yong, Gao Qiang
Huaneng Shandong Shidao Bay Nuclear Power Co., Ltd.
No.9, Shihe Road, Rongcheng, Shandong Province, PRChina
phone: +86-0631-7357705, sunfurui@sdwgs.chng.com.cn

Abstract – The refueling management is an important work of nuclear power plant, directly affecting its safety and economy. At present, the ordinary commercial pressurized water reactor (PWR) nuclear power plant has developed more mature in the refueling management, and formed a set of relatively complete system and methods. The High Temperature Gas-cooled Reactor Pebble-modules Demonstration Project (HTR-PM) has significant differences with the ordinary PWR nuclear power plant in the fuel morphology and the refueling mode. It adopts the spherical fuel element and the on-power refueling. Therefore, the HTR-PM refueling management has its own unique characteristics, but currently there is no mature experience to use for reference across the world. This paper gives a brief introduction to the HTR-PM on power refueling management, including the refueling management system construction, the refueling strategy, the fuel element internal transportation, charging and discharging, etc. It aims at finding the befitting HTR-PM refueling management methods in view of its own unique characteristics in order to ensure the orderly development of the refueling management and the refueling safety.

I. INTRODUCTION

HTR-PM demonstration project, which is in design and construction stage, is an industrialization project formed by Tsinghua University on the basis of HTR-10. HTR-PM is high in inherent safety, good in economy and extensive in usage.

There are significant differences between the HTR-PM fuel elements and the traditional PWR fuel assembly in structure. The HTR-PM fuel elements are all-ceramic coated particle spherical fuel elements, with a diameter of 60mm[1], in which coated fuel particles are uniformly dispersed in a graphite matrix, composing a fuel section and a non fuel section in the external having the same material as the matrix graphite. One fuel element contains over 10,000 coated fuel particles. The core of these coated fuel particles are UO2 kernels, wrapped by three layers of pyrolytic carbon (PyC) and one layer of SiC. The structural diagram of HTR-PM fuel element is shown in Figure 1.

Fig. 1: This is the structural diagram of HTR-PM fuel element.

HTR-PM adopts on power refueling operation mode. A certain number of new fuel elements are charged into the core and the corresponding number of spent fuel elements are discharged. Fuel elements that haven’t reached the burnup limit return to the core. In contrast, PWR adopts off-line refueling, which is usually carried out during overhaul. Although CANDU reactor also adopts on power refueling, it’s number and rate of refueling is far less than HTR-PM. Therefore, the refueling management
of HTR-PM (mainly including the refueling management system, the refueling strategy, the fuel element internal transportation, charging and discharging, etc.) is not the same as that of PWR and CANDU. HTR-PM refueling management must establish the befitting methods in view of its own features to ensure the orderly development of the refueling management and the refueling safety.

II. REFUELING MANAGEMENT SYSTEM

The content of HTR-PM and PWR refueling management are basically the same, but the specific operation of them are not the same. In view of on power refueling operation mode, Huaneng Shandong Shidao Bay Nuclear Power Co., Ltd. (HSNPC) compiled a specialized management procedure “core refueling management”, in which the work content of refueling management, separation of department duties and interface between departments are regulated. All the refueling work will be performed in strict accordance with the management procedure to ensure the implementation of work safe, normative.

III. REFUELING STRATEGY

The refueling strategy of HTR-PM is designed by Institute of Nuclear and New Energy Technology (INET), Tsinghua University. According to the design, refueling strategy (mainly including proportion of fuel elements and graphite balls, refueling speed, discharging burnup, etc.) in different operation stages have certain difference. HSNPC will carry out refueling work mainly based on the refueling strategy designed by INET. Each operation stage refueling strategy is as follows:

III.A. Initial Charge

Initial core is the mixture of low enriched (4.2%) fuel elements and graphite pebbles in a certain ratio. The amount of them is about 400,000 in total.

Initial charge is carried out in the air, and the charging pipe enters into reactor pressure vessel (RPV) through RPV head and the top reflector. Firstly charge the discharge pipe at the bottom of the core with graphite pebbles. After the discharge pipe is filled with graphite pebbles, charge the core with a certain number of graphite pebbles to prevent the fuel pebble broken. Then, keep on charging the mixed pebbles in a certain proportion of fresh fuel pebbles to graphite pebbles until it is filled.

III.B. Transition Cycle

Firstly, replace graphite pebbles with low enriched fuel elements until the core is all filled with low enriched fuel elements. Then replace low enriched fuel elements with high enriched (8.5%) fuel elements until the core is all filled with high enriched fuel elements. The transition stage is complete till this time.

The start-up and transition cycle of the core is carried out in the helium. Firstly, discharge the graphite pebbles in the unloading pipe at the bottom of the core into graphite pebble storage tanks of spent fuel storage system; meanwhile, use dedicated helium compressor to quickly charge the mixing pebbles into the top of the core. After the burn-up measuring system recognizes the first fuel pebbles, the cyclic operation of fuel pebbles and graphite pebbles is started. In the early cyclic process, fuel pebbles and a part of graphite pebbles unloaded from the core return to the core, while the other part of graphite pebbles are unloaded to the graphite pebble storage tanks of the spent fuel storage system, and at the same time, a corresponding number of fresh fuel pebbles are replenished. In this operating mode, the proportion of fuel pebbles to graphite pebbles in the core gradually increases until the core is entirely composed of low-enriched fuel pebbles, and then high-enriched fuel pebbles gradually substitute for low-enriched fuel pebbles in a similar manner.

III.C. Normal Power Operation

In the period of normal power operation the core is entirely composed of high-enriched. Fuel elements within the pebble-bed core flow from top to bottom according to the specific flow line and speed, and then enter discharge pipe on the bottom of the core leading to outside of the RPV. After that, fuel elements discharge in single line through singleness discharger. Some broken fuel elements and other fuel elements that don’t meet the requirements of shape or size will be separated and discharged to the broken fuel element storage tanks. Others will be measured by the burnup measurement system.

The burnup measurement system instrument is based on a mechanically-cooled HPGe detector, including collimator for limiting photon flux at detector and moveable check source for routine calibration verification. Like most traditional BU determination using $^{137}$Cs analysis [2], the BU determination of HTR-PM is done with fuel that has been cooling for a several months.

Fuel elements that have reached the burnup limit will be discharged to the spent fuel element storage tanks and those haven’t reached the burnup limit return to the core. Under the equilibrium state of full power operation, about 6,000 fuel elements are cycled one reactor one day. Meanwhile, 400 new fuel elements are charged and 400 spent elements are discharged.

III.D. Operation Fuel Management Software
Refueling strategy above is composed of core nuclear design screening different schemes and optimizing them. But, the fuel elements in the core flow randomly and transition core state changes dramatically. So nuclear design and actual operation maybe have some difference. For this reason, INET is developing operation fuel management software of HTR-PM, which can collect core operation data in real time by DCS, access current core state, predict the future operation trend and give the refueling proposal. Therefore, when HTR-PM is put into use in the future, refueling scheme will be based on the operation fuel management software in addition to refer to nuclear design. Operators will carry out refueling referring to the software.

IV. OFF-SITE TRANSPORT OF FRESH FUEL ELEMENTS AND TRANSPORT-STORAGE VESSELS

The transportation and storage of HTR-PM fuel element adopts two types vessels, including storage vessels and transport vessels in consideration of economy. The storage vessel is putted into the transport vessel and the combination of them is called transport-storage vessel.

Fuel element manufacturers put the fuel elements that they have produced into transport-storage vessels to transport to the HTR-PM site. After that, the storage vessels are unloaded, and transport vessels and empty storage vessels that have finished refueling return to the fuel element plant. Afterwards, according to the above circulation, the number of transport vessels and the cost of transportation can be substantially reduced.

V. FRESH FUEL ELEMENT STORAGE AND IN-PLANT TRANSPORTATION

V.A. Fresh Fuel Element Storage

Fresh fuel elements are stored in storage vessels, which are putted into storage racks. The racks keep enough distance to prevent critical. The storage vessel adopts the vertical barrel design. Bundle of pipes are used as element tubes. A certain number of fuel elements are packaged into strings (similar to “sugar coated haws”) by polyethylene plastics bags, which are putted into element tubes. It is not only good for reducing the difficulty and cost of packaging, but also good for decreasing collision of elements. The structural diagram of the storage vessel is shown in Figure 2.

HTR-PM fresh fuel element storage facility is divided into fresh fuel bank and fresh fuel charging chamber, in which storage racks are used to store fresh fuel tanks with dry storage method. The storage capacity of the fresh fuel bank can guarantee the need of normal operation for one months. During operation, fresh fuel elements used for charging are supplied from the fresh fuel bank. According to the current design, HTP-PM fresh fuel element storage facility totally has 70 storage tank racks and can store about 210,000 fuel elements in total if each tank stores 3000. The storage capacity of the fresh fuel charging chamber can guarantee the need of normal operation for six months.

V.B. In-Plant Transportation of Fresh Fuel

The in-plant transportation of fresh fuel includes the transportation of fresh fuel tanks from fresh fuel bank to fresh fuel charging chamber and the transportation inside the bank and the charging chamber. The design and layout of storage framework structure provide enough transferring space for fresh fuel tanks, and electric forklifts and trolleys can be used to transfer fresh fuel tanks inside plants. Transportation time and quantity is determined by the actual needs of the HTR-PM.

VI. CHARGING AND DISCHARGING

VI.A. Charging

In view of reserve, fresh fuel feeding subsystem is designed as two sets of identical procedures, which are arranged in the fresh fuel charging chamber. In the charging operation, firstly forklifts and trolleys are used to transfer fresh fuel tanks from the storage racks in the charging chamber to reclaiming racks. After that the covers are opened, and the monorail crane in the charging chamber is used to put the covers on the tank cover bracket of reclaiming racks. Afterwards professional fuel operators take out the fuel pebble strings in plastic bags and complete operations, such as the bags opening of fresh fuel spheres and visual inspection.
Fresh fuel pebbles go into reactor by fuel handling system automatically.

VI.B. Discharging

Spent fuel elements discharged from the reactor core by the fuel handling system are put into the spent fuel storage tank in the steel shield. After the spent fuel storage tank is full, weld the tank cap, and then transport and hoisting it to the spent fuel storage shaft. The whole process is all completed automatically through the spent fuel handling system. Operators only need to remote operation and supervision.

VII. SPENT FUEL ELEMENTS STORAGE

HTR-PM spent fuel element adopts dry storage, regardless of outward transportation in power plant design life period. Spent fuel storage areas are divided into 3 parts (Figure 3): the buffer storage area, the first intermediate storage area and the second intermediate storage area. The newly loaded spent fuel storage tank is put into the buffer storage shaft for some years and later transferred to the first or second storage shaft. Each spent fuel storage tank can hold about 40,000 pebbles, which is not considered to be transported outside during operation years.

Spent fuel storage rooms set up three kinds of cooling ways: closed forced ventilation, open forced ventilation and open natural ventilation. During normal operation, the spent fuel buffer storage area adopts forced ventilation, and the intermediate storage area adopt the method of open natural ventilation to exhaust waste heat. Under accident conditions, even closed forced ventilation and open forced ventilation can not run, all storage areas can also exhaust the waste heat only through open natural ventilation, ensuring the safety of spent fuel element storage.

VIII. STATISTICS OF FUEL ELEMENTS’ QUANTITY AND POSITION DURING THE REFUELING

HTR-PM use the on power refuelling operation mode. The number of daily refueling elements is large and the operation of refueling is frequent. So there is a risk that fuel elements may be taken away by human or loss. Therefore, counting the number and position of fuel elements accurately during refueling, ready for the physical inventory, is particularly important.

During fuel elements transportation, charging and discharging process, operators need to record the new/spent fuel storage tank number, location, quantity and the number of new fuel elements charged into the core. Each spent fuel handling system pipes are arranged many ball counter, which can count the amount of fuel elements in and out of the core through each line. Finally, collect and conclude artificial counting data and ball counter data to know the number of new fuel elements, discharging spent fuel elements, fuel elements inside the reactor core and the number and location of key points’ fuel elements, etc.

IX. CONCLUSION

In view of on power refueling operation characteristics and referring to the relevant methods of PWR refueling management experience, we can ensure the safety of the HTR-PM refueling process and meet the requirements of relevant national laws and regulations through establishing refueling management system, reasonable and feasible method of refueling.

REFERENCES