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Direct reuse of spent nuclear fuel

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HIGHLIGHTS

- A new design for the PWR assemblies for direct use of spent fuel was proposed.
- The PWR spent fuel will be transferred directly (after a certain cooling time) to CANDU reactors.
- The proposed assembly has four zircaloy-4 tubes contains a number of CANDU fuel bundles (7 or 8 bundles per tube) stacked end to end.
- MCNPX is used for the calculations that showed that the burnup can be increased by about 25%.
- Acceptable linear heat generation rate in hot rods and improved Pu proliferation resistance.

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ABSTRACT

In this paper we proposed a new design for the PWR fuel assembly for direct use of the PWR spent fuel without processing. The PWR spent fuel will be transferred directly (after a certain cooling time) to CANDU reactors which preferably built in the same site to avoid the problem of transportations. The proposed assembly has four zircaloy-4 tubes contains a number of CANDU fuel bundles (7 or 8 bundles per tube) stacked end to end. Each tube has the same inner diameter of that of CANDU pressure tube. The spaces between the tubes contain low enriched UO_2 fuel rods and guide tubes. MCNPX code is used for the simulation and calculation of the burnup of the proposed assembly. The bundles after the discharge from the PWR with their materials inventories are burned in a CANDU cell after a certain decay time. The results were compared with reference results and the impact of this new design on the uranium utilization improvement and on the proliferation resistance of plutonium is discussed. The effect of this new design on the power peaking, moderator temperature coefficient of reactivity and CANDU coolant void reactivity are discussed as well.

1. Introduction

The development of the fuel cycle technology for recycling the spent fuel of nuclear reactors has a particular importance to improve the uranium utilization, to reduce the high level nuclear waste and to reduce the amount of plutonium in spent fuel per unit energy. Pressurized water reactors (PWRs) that represent about 62% (International Atomic Energy Agency, 2006) of the operational reactors generate about 68% of the electrical power produced from nuclear reactors. PWRs uses fuel enriched up to 5 wt% and discharge the fuel with a significant amount of fissile isotopes (U-235, Pu-239 and Pu-241), often about twice that of natural uranium (Chad and Bollmann, 1998). The average discharge fuel burnup in PWR has increased from about 30 MWd/kgU in the 1970s to about 50 MWd/kg today with increase of the fuel average enrichment from about 3 w/o to about 4.5 w/o (Xu, 2003). The burnup licensing is mainly related to the corrosion and hydrogen pickup of the clad and the high burnup properties of the fuel and the dimensional changes of the fuel assembly/bundle structure. The licensing limit of the fuel burnup is averaged on the fuel assembly, and it is from 60 to 70 MWd/kgU for light water reactors (LWRs) (IAEA-TECDOC-1299, 2002).

There are two methods to recycling the fissile isotopes in the PWR spent fuel. First method is by extracting the fissile isotopes from the spent fuel through the chemical processing (IAEA-TECDOC-1587, 2008) and recycling them in the reactors. Second method is the direct use of spent PWR fuel in CANDU reactors (DUPIC) which is originally proposed in Korea (Chad and Bollmann, 1998; Myung et al., 2006; Jeong and Choi, 2000). In DUPIC the PWR fuel is stored for a period of cooling time. Then the spent fuel is shipped to a special plant to be re-fabricated into CANDU fuel bundles using a dry processing such as AIROX plant (Zhao et al., 1999). In this plant, the cladding is punctured and fission gases are captured. The cladding is removed and the fuel pellets are transferred

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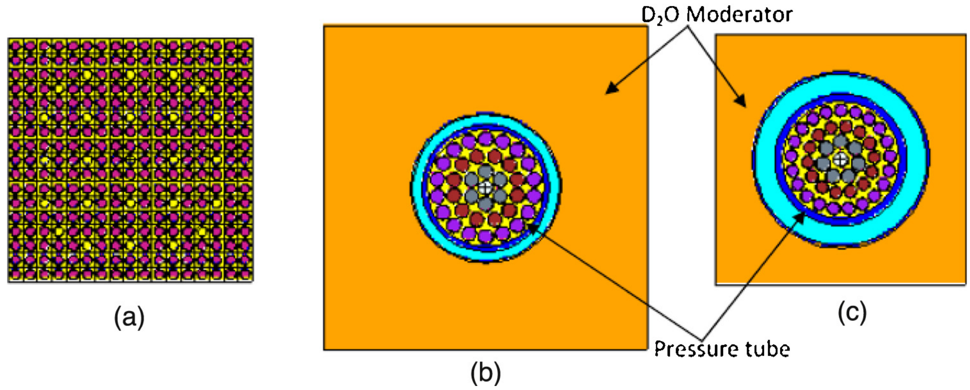

Fig. 1. MCNP simulation of: (a) Westinghouse PWR assembly, (b) lattice cell of CANDU-6 and (c) lattice cell of ACR-700.

to a furnace at peak temperature of 1600 C where the volatile fission products are removed while the pellets are reduced to a fine powder. This powder is milled, shaped, and sintered into CANDU fuel pellets used to build the fuel bundles. The high neutron economy on-power refueling CANDU reactor is originally designed for natural uranium fuel or slightly enriched uranium fuel. Therefore, considerable amount of fuel burnup can be obtained from DUPIC. Another example of direct use of PWR spent fuel in CANDU reactors is cutting the PWR fuel elements into CANDU length (~50 cm), straighten them, and then weld new end-caps to the ends. The smaller diameter of PWR elements would enable the use of a 48- or 61-element fuel bundle which would significantly reduce the linear element ratings compared with those of a 37-element bundle and enhance fuel performance, and would help to accommodate the variation in fissile content between elements (Zhonsheng and Boczar, 2014).

The core of PWR is built from long fuel bundles (assemblies) running the length of the core and arranged in a near-cylindrical array, the entire reactor core is a single large pressure vessel containing the light water, which acts as moderator and coolant. The CANDU reactor is built from modular horizontal fuel channels surrounded by a heavy water moderator. CANDU fuel bundle contains 27, 37 or 43 (or more) half meter long fuel tubes with 12 such bundles lying end to end in a pressure tube. Fig. 1 shows the differences between a typical PWR and CANDU fuel bundles. The power distribution throughout the PWR assembly is more uniform than the CANDU fuel bundle since, in CANDU reactor the fission neutrons are thermalized in the moderator outside the fuel channel and the fission rate is decreased from the outer pins to the central pin. Many parameters affect the power distribution across the CANDU bundle. These parameters include fuel enrichments, lattice pitch size, fuel pin diameter and number of fuel pins. Increasing the fuel enrichment increases the pin power peaking factor due to the self-shielding of the fuel pins and therefore CANDU reactors only use slightly enriched uranium fuel. CANDU-6 burns natural uranium to about 7.5 MWd/kg while the 700 MWe advanced CANDU reactor (ACR-700) uses 2.1 w/o enriched uranium and has an average burnup of 20.5 MWd/kg (Lam, 2009).

Another important parameter affecting the design of CANDU reactors is the coolant void reactivity. The coolant void coefficient of reactivity is negative in light water reactors, since the coolant and the moderator are the same fluid in the reactor pressure vessel. In pressure tube reactors the moderator remains when the coolant is lost, and consequently the void reactivity may be positive as in the case of CANDU reactors. Many methods are proposed for the reduction of coolant void coefficient of reactivity. The main two methods are decreasing the moderator volume and use of a burnable poison like dysprosium in the central pin (Marczak, 1990; Whitlock, 1995).

In this paper we proposed a new design for the PWR assemblies for direct reuse of the PWR spent fuel without processing. The PWR spent fuel will be transferred directly (after a certain cooling time) to CANDU reactors which preferably built in the same site to avoid the problem of transportations. Safety parameters such as power peaking, moderator temperature coefficient of reactivity and CANDU coolant void reactivity for the new design will be discussed.

2. Proposed design

A Westinghouse PWR fuel assembly has been selected as reference for this study. The fuel assembly consists of UO_2 fuel rods bundled in 17 × 17 pins fuel assembly (21.5 cm pitch) as shown in Fig. 1a. The design proposed is shown in Fig. 2. Four zircaloy-4 tubes contains a number of CANDU fuel bundles (7 or 8 bundles per tube) stacked end to end. Each tube has the same inner diameter of that of CANDU pressure tube (5.17 cm) and with wall thickness of 1.3 mm. The spaces between the tubes contain UO_2 fuel rods with enrichment lower than that in the four zircaloy-4 tubes and guide tubes as shown in the figure. The PWR with the new design fuel assembly can be considered as a vertical tubes reactor

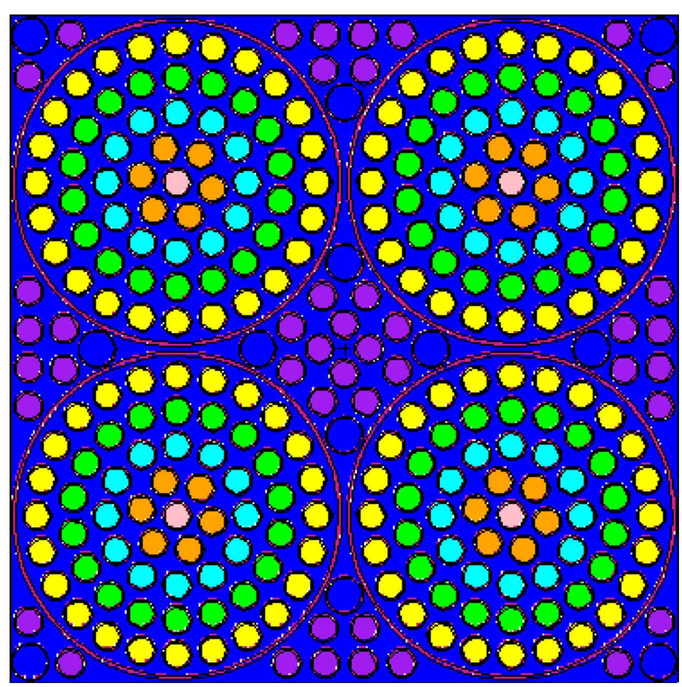

Fig. 2. MCNP model of the proposed PWR assembly for direct spent fuel reuse.