Applied Mechanics and Materials
ISSN: 1662-7482, Vol. 575, pp 653-657
doi:10.4028/www.scientific.net/AMM.575.653

Submitted: 2014-04-28
Accepted: 2014-04-28
Online: 2014-06-25

SUPEL Scenario for PWR Spent Fuel Direct Recycling Scheme

Abdul Waris[1,a], Syeilendra Pramuditya[1,b], Indarta Kuncoro Aji[2,c], Rahadi Wirawan[2,d], Nuha[3,e]

[1]Nuclear Physics & Biophysics Research Division, Department of Physics, Institut Teknologi Bandung, Jl. Ganesa 10, Bandung 40132, Indonesia

[2]Department of Physics, Institut Teknologi Bandung, Jl. Ganesa 10, Bandung 40132, Indonesia

[3]Agency for Assessment and Application of Technology, Kompleks PUSPITEK LABTIAB, Gedung 611, Serong, Tangerang, Indonesia

[a]awaris@fi.itb.ac.id, [b]syeilendra@fi.itb.ac.id, [c]indartaaji@gmail.com, [d]rwirawan@yahoo.co.id, [e]nuha_sf21@yahoo.co.id

Keywords: Direct recycling, PWR, spent fuel, SUPEL, criticality

Abstract. Study on SUPEL (Straight Utilization of sPEnt LWR fuel in LWR system) scenario for PWR spent fuel direct recycling scheme has been performed. Several spent PWR fuel compositions in loaded fuel has been investigated to achive the criticality of reactor. The reactor can obtain it criticality for 4.5 a% of UO_2 enrichment with at maximum 8.0 a% of spent fuel fraction in loaded fuel. The neutron spectra become harder with the raising of UO_2 enrichment in the loaded fresh fuel as well as the increasing of the fraction of spent fuel in the core.

Introduction

A part from the current issue regarding Fukushima nuclear accident on March, 2011, a sustainable utilization of nuclear energy is required from the perspective of world energy need, global warming and limitation of resources. There are three main concerns which related to nuclear energy, namely: safety, non-proliferation, and spent fuel (waste) management. However, nuclear spent fuel management is regarded as the most essential problem in the nuclear energy use [1-2]. Recycling of the nuclear spent fuel is an interesting option for handling the nuclear spent fuel. Recycling may increase the public acceptance about nuclear energy. Nevertheless, the spent fuel should be reprocessed to extract uranium and plutonium together with minor actinides (MA), and then separate them from other nuclides/isotopes such as LLFP, prior to recycling process. This process is known as a reprocessing or partitioning stage.

Since the spent fuel is hazardous high level waste, partitioning is high-priced and requires remote handling [3]. Moreover, only a few countries are allowed to have a reprocessing plant. Whenever country likes Indonesia choose to utilize nuclear energy, it should to find another manner to manage the nuclear spent fuel. Korea has offered the DUPIC (Direct Utilization of spent PWR fuel In CANDU) concept. But, two types of nuclear power plants, i.e., pressurized water reactor (PWR) and CANadian Deuterium Uranium reactor (CANDU) are needed to realize DUPIC concept [4]. This idea probabbly becomes very expensive for some countries.

In our previous study, we have proposed a scheme of direct recycling of the spent PWR fuel in PWR system, under the concept that we have called as a SUPEL (Straight Utilization of sPEnt LWR fuel in LWR system) scenario [5]. Here, direct recycling means that the recycling of the spent fuel without the reprocessing stage.

In the present study, we evaluate the SUPEL scenario for PWR spent fuel direct recycling scheme in more detail. Several spent PWR fuel compositions in loaded PWR fuel have been evaluated to achieve the criticality of reactor.

Methodology

The nuclide number density of *i*-th nuclide in the PWR core, n_i, can be determined by using the following Eq. (1) [2].

$$\frac{dn_i}{dt} = -(\lambda_i + \phi\sigma_{a,i} + r_i)n_i + \sum_j \lambda_{j\to i} n_j + \phi \sum_k \sigma_{k\to i} n_k + s_i \quad (1)$$

where ϕ: neutron flux, λ_i: decay constant of i-th nuclide, r_i: discharge constant of i-th nuclide, $\lambda_{j\to i}$: decay constant of j-th nuclide to produce i-th nuclide, $\sigma_{k\to i}$: microscopic of nuclear transmutation cross-section of k-th nuclide to produce i-th nuclide, s_i: supply rate of i-th nuclide, $\sigma_{a,i}$: microscopic of nuclear absorption cross-section of i-th nuclide.

Table 1 shows the design parameter of studied PWR [2].

Table 1. PWR design parameters

Thermal power output	3000 MWth
Average cell power density	100 Wcm^{-3}
Fuel pellet diameter	8.0 mm
Fuel rod diameter	9.6 mm
Pin pitch	11.8 mm
Fuel type	Oxide
Cladding	Zircaloy-4
Coolant	H_2O

In the present study, the cell and burnup calculations were performed by using the SRAC 2002 code [6] with the nuclear data library from JENDL 3.2 for these both calculation schemes [7].

The SUPEL scenario can be concisely described as the following Fig. 1 [5]. PWR is operated to achieve the 33 GWd/ton burnup. Subsequently, the spent PWR fuel is collected in the spent fuel interim storage for five years cooling. After that, the PWR spent fuel is mechanically separated into two major streams: (1) the UO_2 with actinides and fission products and (2) the spent fuel cladding. The UO_2 with fission products and actinides is fabricated into PWR spent fuel assemblies. This separation process was adopted from DUPIC fuel process [4, 8]. Finally, this spent PWR fuel assemblies are loaded into PWR core together with fresh enriched UO_2 fuel assemblies. In other words, there are two types of loaded fuels in the core, namely: the fresh fuel and the spent PWR fuel.

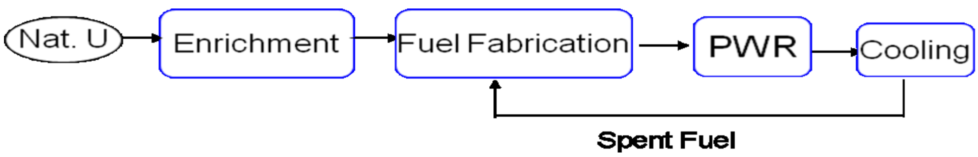

Fig 1. Diagram of SUPEL Scenario

In our previous study, the total fraction of PWR spent fuel was varied from 2.0 a% to 20.0 a%, and U-235 enrichment of the fresh UO_2 fuel was changed from 3.5 a% to 5.0 a% [5]. While, In the present study, the total fraction of spent fuel was changed from 5.0 a% to 20.0a %, and U-235 enrichment of the fresh UO_2 fuel was changed from 3.0 a% to 5.0 a%.

In the present study, for more confident condition, the criticality of the reactor has be judged if the effective multiplication factor (*k-eff*) is higher than unity during the whole lenght of cycle. However, in our previous investigation regarding SUPEL scenario [5], the criticality of the reactor was determined when the effective multiplication factor during the first two-third of cycle lenght is higher than one.

Table 2 presents the list of 87 nuclides and 1 pseudo nuclide in PWR spent fuel (nuclear wastes). These nuclides are the whole nuclides which provided by JENDL 3.2 nuclear data library.

Table 2. List of nuclides in spent fuel

Kr-83	Ru-101	Pd-107	I-131	Cs-135	Pm-147	Sm-151	Gd-156	Np-237	Am-242
Zr-93	Ru-102	Pd-108	I-135	La-139	Pm-148m	Sm-152	Gd-157	Np-239	Am-243
Zr-96	Ru-103	Ag-109	Xe-131	Ce-141	Pm-148	Sm-147	Gd-158	Pu-238	Cm-242
Mo-95	Ru-104	Cd-110	Xe-132	Pr-141	Pm-149	Eu-153	B-10	Pu-239	Cm-243
Mo-97	Ru-105	Cd-111	Xe-133	Pr-143	Pm-151	Eu-154	Pseudo	Pu-240	Cm-244
Mo-98	Rh-103	Cd-113	Xe-135	Nd-143	Sm-147	Eu-155	U-235	Pu-241	Cm-245
Mo-99	Rh-105	In-115	Xe-136	Nd-145	Sm-148	Eu-156	U-236	Pu-242	
Mo-100	Pd-105	I-127	Cs-133	Nd-147	Sm-149	Gd-154	U-237	Am-241	
Tc-99	Pd-106	I-129	Cs-134	Nd-148	Sm-150	Gd-155	U-238	Am-242m	

Results and Discussion

Figs. 2, 3 and 4 show the effective multiplication factor (*k-eff*) for UO_2 enrichments in loaded fresh fuel of 3.0 a%, 4.0 a%, and 4.5 a%, respectively. As has been stated earlier, the total fraction of the spent fuel was varied from 5.0 a% to 20.0 a%. As can be seen from these figures, for 3.0 a% and 4.0a% of UO_2 enrichments in the loaded fresh fuel, the reactor can not obtain its criticality. However, for 4.5 a% of UO_2 enrichment, the criticality can be achieved for up to 8.0% of spent fuel in the loaded fuel. As presented in Table 2, the spent fuel consists of several strong poison nuclides such as U-236 which absorbs neutron strongly. To overwhelme this problem, the greater UO_2 enrichment in the fresh fuel is demanded.

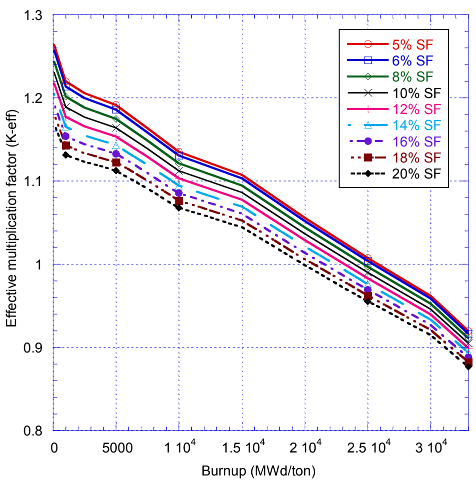

Fig. 2. k-eff for 3.0 a% UO_2 enrichment

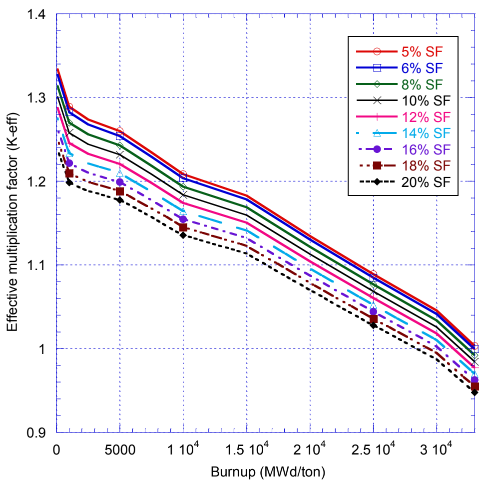

Fig. 3. k-eff for 4.0 a% UO_2 enrichment

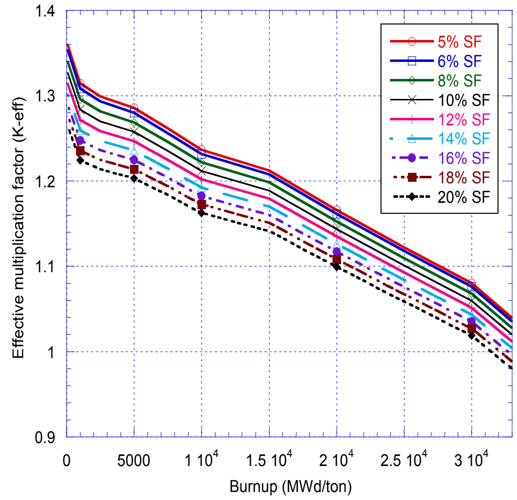

Fig. 4. k-eff for 4.5 a% UO_2 enrichment

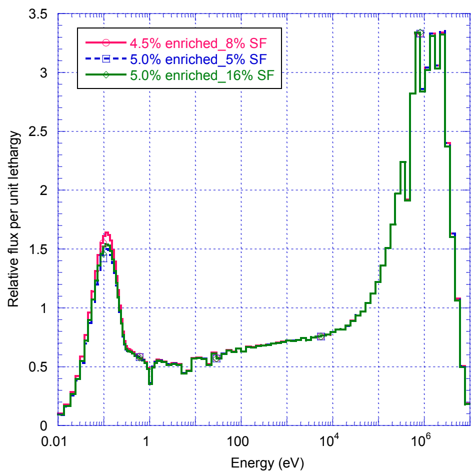

Fig. 5. Comparison of neutron spectra

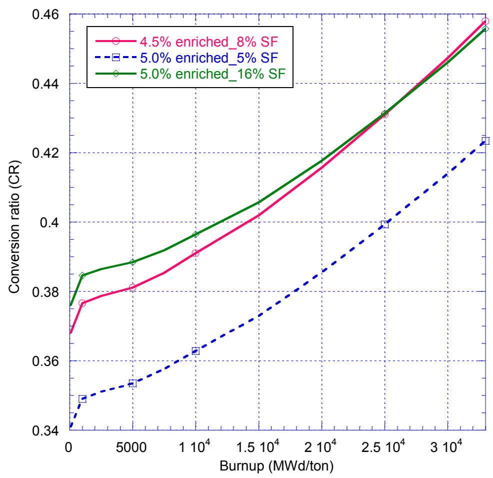

Fig. 6. Comparison of conversion ratio

The comparison of neutron spectra for 4.5 a% of UO_2 enrichment with 8.0 a% of spent fuel, 5.0 a% of UO_2 enrichment with 5.0 a% of spent fuel, and 5.0 a% of UO_2 enrichment with 16.0 a% of spent fuel in the loaded fresh fuel is presented in Fig 5. For all three cases, in thermal energy region (energy < 1 eV), the relative flux per unit lethargy reduces with the enlarging of the spent fuel fraction in the core. In other words, the neutron spectra become harder (shifts to the high energy region) with the escalating of trans-uranium (TRU) nuclides in the reactor. This may due to the larger microscopic absorption cross-section of TRU, such as Pu-239 and Pu-241 in the thermal energy region. This fact has been reported in our previous study [5]. Moreover, the neutron spectra also become harder with the increasing uranium enrichment in the loaded fresh fuel.

Fig 6 demonstrates the comparison of a conversion ratio (CR) for 4.5 a% of UO_2 enrichment with 8.0 a% of spent fuel, 5.0 a% of UO_2 enrichment with 5.0 a% of spent fuel, and 5.0 a% of UO_2 enrichment with 16.0 a% of spent fuel in the loaded fresh fuel. For the same UO_2 enrichment, CR increases with the raising of spent fuel fraction in the loaded fuel. Conversion ratio is the ratio between production rate and absorption rate of fuel nuclides and can be calculated from the following equation [9].

$$CR = \frac{Capture\_rate\_of\_({}^{238}U + {}^{238}Pu + {}^{240}Pu)}{Absorption\_rate\_of\_({}^{235}U + {}^{239}Pu + {}^{241}Pu) + Decay\_rate\_{}^{241}Pu} \quad (2)$$

The decay rate of ^{241}Pu was considered in calculating CR since the half-life of this nuclide is only 14.4 years.

Conclusions

SUPEL scenario for PWR spent fuel direct recycling scheme has been evaluated. The reactor can obtain it criticality for 4.5 a% of UO_2 enrichment with at most 8.0 a% of spent fuel fraction in loaded fuel. The neutron spectra become harder with the enlarging of UO_2 enrichment in the loaded fresh fuel as well as the augmenting of the amount of spent fuel in the core.

Acknowledgment

This work was supported by Competence Research Grant *(Hibah Kompetensi)* 2010 and Competitive Research Grant (*Hibah Bersaing*) 2011, Directorate General of Higher Education, Minister of National Education of Indonesia.

References

[1]. D. Warin, Status of the French Research Program on Partitioning and Transmutation, J. Nucl. Sci. Technol. 44, 3 (2007), pp. 410-414

[2]. A. Waris and H. Sekimoto, Characteristics of several equilibrium fuel cycles of PWR, J. Nucl. Sci. Technol., 38 (2001), pp.517-526

[3]. IAEA, “Thorium based fuel options for the generation of electricity: Developments in the 1990s”. IAEA-TECDOC-1155 (2000), Vienna, Austria

[4]. W. I. Ko, H. D. Kim, M. S. Yang, RadioactiveWaste Arisings from Various Fuel Cycle Options, J. Nucl. Sci. Technol. 39, 2 (2002), pp. 200-210

[5]. A. Waris, et. al., Preliminary study on direct recycling of spent PWR fuel in PWR system, AIP Conference Proceedings, 1448 (2012), pp. 135-141

[6]. K. Okumura, et. al., SRAC (Ver.2002): The Comprehensive neutronics calculation code system, Japan Atomic Energy Research Institute, Tokai-mura, Japan (2002).

[7]. T. Nakagawa, T., et. al., Japanese Evaluated Nuclear Data Library Version 3 Revision-2: JENDL-3.2, J. Nucl. Sci. Technol., 32 (1995), pp. 1259-1271

[8]. C. J. Park, et. al., Irradiation tests and post-irradiation examinations of DUPIC fuelAnnals of Nuclear Energy, 35 (2008), pp. 1805 – 1812

[9]. A. Waris, H Sekimoto, G. Kastchiev, Influence of Moderator-to-Fuel Volume Ratio on Pu and MA Recycling in Equilibrium Fuel Cycles of PWR, Proc. Intern. Conf. on the New Frontiers of Nuclear Technology : Reactor Physics, Safety and High-Performance Computing, PHYSOR 2002, (2002) 13d-03, Oct 7-1-10, Seoul, Korea,