Annals of Nuclear Energy 75 (2015) 527–535

Contents lists available at ScienceDirect

Annals of Nuclear Energy

journal homepage: www.elsevier.com/locate/anucene

Dry storage of spent nuclear fuel in UAE – Economic aspect

Sara Al Saadi [a,*], Yongsun Yi [b]

[a] Federal Authority for Nuclear Regulation, Abu Dhabi, United Arab Emirates
[b] Department of Nuclear Engineering, Khalifa University, Abu Dhabi, United Arab Emirates

ARTICLE INFO

Article history:
Received 24 June 2014
Received in revised form 30 August 2014
Accepted 1 September 2014
Available online 20 September 2014

Keywords:
Nuclear fuel cycle
Dry storage
Economic analysis

ABSTRACT

Cost analysis of dry storage of spent nuclear fuel (SNF) discharged from Barakah nuclear power plants in the UAE was performed using three variables: average fuel discharge rate (FD), discount rate (d), and cooling time in a spent fuel pool (T_{cool}). The costs of dry storage as an interim spent fuel storage option in the UAE were estimated and compared between the following two scenarios: Scenario 1 is 'accelerated transfer of spent fuel to dry storage' that SNF will be transferred to dry storage facilities as soon as spent fuel has been sufficiently cooled down in a pool for the dry storage; Scenario 2 is defined as 'maximum use of spent fuel pool' that SNF will be stored in a pool as long as possible till the amount of stored SNF in the pool reaches the capacity of the pools and, then, to be moved to dry storage. A sensitivity analysis on the costs was performed and multiple regression analysis was applied to the resulting net present values (NPVs) for Scenarios 1 and 2 and ΔNPV that is difference in the net present values between the two scenarios. The results showed that NPVs and ΔNPV could be approximately expressed by single equations with the three variables. Among the three variables, the discount rate had the largest effect on the NPVs of the dry storage costs. However, ΔNPV was turned out to be equally sensitive to the discount rate and cooling period. Over the ranges of the variables, the additional cost for accelerated fuel transfer (Scenario 1) ranged from 86.4 to 212.9 million $. Calculated using the maximum difference (212.9 M$) between the two scenarios, the accelerated fuel transfer to dry storage could incur the additional electricity rate 8.0×10^{-5} USD/kWh, which is not considered to be significant, compared to the overall electricity generation cost.

1. Introduction

Owing to rapid economic and demographic growth in the United Arab Emirates (UAE), electricity demand has grown by 8.5% per year and is expected to require 40 GWe in 2020 (Krane, 2014). Considering the continuously growing electricity demand, in April 2008, the UAE independently published a comprehensive policy on nuclear energy. Accordingly, a Federal Law by Decree No. 6 of 2009 concerning the peaceful uses of nuclear energy came into effect in September 2009 (UAE Nuclear Law, 2009). This UAE nuclear law established the Federal Authority for Nuclear Regulation (FANR) as the UAE's nuclear regulatory body in September 2009 and a Nuclear Energy Program Implementation Organization which set up the Emirates Nuclear Energy Corporation (ENEC) in December 2009 (UAE Government, 2008). In December 2009 ENEC announced that it had selected a bid from the KEPCO-led consortium for four APR-1400 reactors, to be built at one site. The construction license for units 1 & 2 at Barakah on the coast 300 km west of Abu Dhabi city was issued by FANR and the first batch of nuclear safety concrete for Barakah Unit 1 was poured in July 2012 (IAEA, 2013). Currently, the UAE is on track to commission the first of four planned nuclear power plants in May, 2017 and then the first reactor will start discharge of spent nuclear fuel in 2018 or 2019 depending on its refueling schedule.

In Barakah nuclear power plants, spent nuclear fuel is supposed to be stored at reactor sites in spent fuel pools and then in dry storage systems. The spent fuel will be stored in a water filled pool constructed of concrete with interior stainless steel walls and the storage racks in the spent fuel pool are designed to safely hold up to 20 years of spent fuel generation (FANR, 2012). According to the current conception of the spent fuel management in the UAE, the spent nuclear rods will be stored in above-ground depots at the nuclear power plant in Abu Dhabi until at least 2123 or alternatively, they can be sent abroad for recycling or disposal (7days, 2013). For the dry storage they conceive that it could take 20 years for spent fuel rods to cool down before being placed in concrete containers for dry storage. The cooling period of spent fuel in pools required for its transfer to dry storage depends on the

* Corresponding author. Address: PO Box 112021, Abu Dhabi, United Arab Emirates.
E-mail address: sara.alsaadi@fanr.gov.ae (S. Al Saadi).

http://dx.doi.org/10.1016/j.anucene.2014.09.003
0306-4549/© 2014 Published by Elsevier Ltd.

designs of dry storage systems and the characteristics of discharged spent fuel such as thermal load and burnup of discharged spent fuel (IAEA, 2009). According to US NRC (US NRC, 2013), fuel is typically cooled at least 5 years in the pool before transfer to cask and also US NRC has authorized transfer as early as 3 years; the industry norm is about 10 years. Even though the exact characteristics of spent fuel discharged from Barakah nuclear power plants are unknown now, according to the practice in the USA, spent fuel in the UAE could be moved to dry storage systems earlier than 20 years. Transferring spent fuel from a pool to a dry storage system offers several benefits (US Government Accountability Office, 2012). A chief advantage of transfer of spent fuel from densely packed pools to dry storage is to increase the safety margin for events (either severe accidents or terrorist attacks) that cause a loss of pool water inventory and result in spent fuel heat-up to the zirconium ignition temperature, a self-sustaining zirconium fire, fuel damage and massive radiological release (Lyman, 2012). On the other hand, the transfer presents some challenges. According to GAO-12-797 (US Government Accountability Office, 2012), four challenges could be conceived: (i) potential radiation doses to workers during loading operations, (ii) increase in potential for accidents due to more movements of equipment, (iii) time constraints related to routine dry storage loading operation time, and (iv) increase in cost. The first three challenges are technical issues and the last one is an economic issue.

In Barakah nuclear power plants, we could have two scenarios in terms of the timing of the spent fuel transfer to dry storage. After 20 years the spent fuel pools at Barakah reach their capacity and therefore it should be started to move spent fuel to dry storage systems unless capacity expansion of spent fuel pools is considered. As another scenario, the transfer of spent fuel to dry storage could be implemented just after spent fuel cools down sufficiently, which is expected to be much earlier than 20 years as mentioned above. In this study, costs of the dry storage of SNF in the UAE for the two scenarios were deliberated and analyzed. In cost analysis of dry storage of spent fuel, the price of dry storage systems takes a major share (Kessler, 2009). In the USA, there are two basic types of dry storage systems: bare-fuel (thick-walled or metal shielded) casks and canister-based systems consisting of a (thin-walled) canister inside a (thick-walled) cask or storage module (concrete-shielded) (US Nuclear Waste Technical Review Board, 2010). This study assumes a canister based system consisting of a metallic canister and concrete overpack (referred to as 'concrete casks' hereafter) and the cost analysis was performed for concrete casks. Using cost data available in literature, the net present values (NPVs) and levelized unit costs (LUCs) for the two scenarios were calculated and compared. For uncertainty analysis, three variables were adopted: average fuel discharge rate, FD (kg HM/GWd); discount rate, d (%) and cooling period in pools, T_{cool} (year). This paper discusses the influence of each variable on the overall dry storage costs for the two scenarios and the additional cost that the accelerated transfer of spent fuel to dry storage incurs in Barakah nuclear power plants.

2. Approach and methodology

2.1. Projection of discharged spent fuel

The total cost of concrete casks for dry storage is proportional to the amount of spent fuel stored in the systems. The annual amount of spent fuel discharge can be calculated by (Kang, 1999):

$$SF_t = \frac{NC_t \times 365 \times CF_t}{TE_t \times BU_t} \quad (1)$$

where SF_t is the annual amount of spent fuel discharged in year t (tHM – ton heavy metal), NC_t the net nuclear capacity in year t (GW_e), CF_t the capacity factor in year t, TE_t the thermal to electrical efficiency in year t, and BU_t the average discharge burnup in year t (GWd/tHM). Among the factors that determine the annual discharge rate of spent fuel, the exact values of the capacity factor and discharge burnup will not be available until spent fuel is discharged. Since both of the factors vary independently, a new factor, FD_t (fuel discharge rate), was introduced as follows:

$$FD_t = \frac{CF_t}{BU_t} \times 1000 \quad (2)$$

FD_t is the average fuel discharge rate defined as the daily amount (kg) of discharged spent fuel per GW_{th}. Using FD_t, Eq. (1) is simplified to:

$$SF_t = \frac{NC_t \times 365}{TE_t} \times FD_t. \quad (3)$$

Based on the discharged SNF projection, the required amount of dry storage casks was calculated.

2.2. Cost analysis of dry storage of spent fuel

The cost analysis of spent fuel dry storage was performed on two scenarios. The first scenario is 'the accelerated spent fuel transfer to dry storage' that spent fuel will be moved to dry storage facilities as soon as SNF has been sufficiently cooled down for the dry storage. The second scenario is defined as 'the maximum use of spent fuel pool' that SNF will be stored as long as possible till the pools become full of SNF and, then, to be moved for dry storage systems (Fig. 1). The time period for the cost projection of SNF dry storage was divided into three phases as shown in Fig. 2:

- Preconstruction phase (design, engineering, analysis, licensing);
- Construction phase (Construction of facilities);
- Operation phase (Loading and storage).

In the cost projection of the two scenarios the following assumptions were used:

- Commercial operations of the nuclear power plants are scheduled in 2017 and 2018 for units 1 & 2, respectively, followed by 2019 and 2020 for units 3 & 4. To simplify the calculation the 4 units are assumed to be operating during the same period from 2017 to 2077, discharging equal amount of SNF every year;
- The dry storage will be installed on site (AFR-RS: away-from-reactor on site storage) (IAEA, 1999), so no additional cost for the away from reactor (AFR-OS: away-from-reactor off site storage) option is necessary except for transportation within a reactor site;

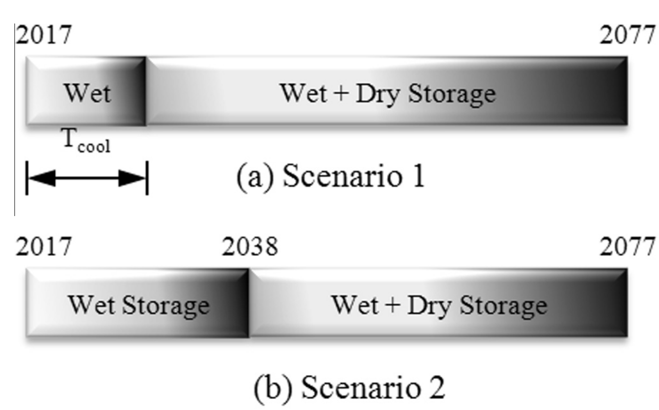

Fig. 1. Two scenarios of SNF dry storage used in this study.