Annals of Nuclear Energy 60 (2013) 172–180

Contents lists available at SciVerse ScienceDirect

Annals of Nuclear Energy

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

Comparison of the once-through and closed nuclear fuel cycles with regard to waste disposal area required in a geological repository

Banu Bulut Acar *, H. Okan Zabunoğlu

Hacettepe University, Department of Nuclear Engineering, Beytepe, Ankara 06800, Turkey

ARTICLE INFO

Article history:
Received 8 January 2013
Received in revised form 26 April 2013
Accepted 30 April 2013
Available online 3 June 2013

Keywords:
Nuclear fuel cycle
Nuclear waste
Geological disposal
Waste repository
Monteburns
Ansys

ABSTRACT

This study aims to compare the once-through and the standard closed nuclear fuel cycles with respect to waste disposal area required (for spent fuel and high-level waste) in a permanent geological waste repository. Utilizing the code MONTEBURNS, relevant compositions and decay heats are obtained for several selected burnup values. Then, using the code ANSYS, disposal areas needed for waste types under consideration are determined. Results are expressed in terms of "total electrical energy (MWe-yr) produced per unit waste disposal area (m^2)", which is taken as the decisive parameter to compare the two cycles. It can be concluded that: the once-through cycle displays an advantage up to nearly a burnup of 40,000 MWd/t with regard to waste (spent fuel and high-level waste) disposal density; however, at higher burnups, the standard closed cycle is better than the once-through.

© 2013 Elsevier Ltd. All rights reserved.

1. Introduction

This study is an effort in comparing the Once-Through Cycle (OTC) and the standard Closed Cycle (CC) with regard to disposal area required in a waste repository. First, disposal areas needed per unit mass of spent fuel (SF) and high-level waste (HLW) in a deep geological repository are determined. Then, to compare OTC and CC, the disposal areas are related to the amounts of SF and HLW to be isolated and the electricity generated in each cycle.

1.1. Background

A 1000-MWe PWR loaded with 3.3 w/o (weight percent) enriched UO_2 fuel, with a discharge burnup of 33,000 MWd/tU and with an irradiation time of 1000 days is taken as the reference. SF discharged in the reference case consists of about 95.5 w/o U, 1 w/o Pu, 3.5 w/o fission products and other actinides. The U in SF contains around 0.85 w/o U-235. Nearly 70 w/o of Pu in SF is composed of fissile isotopes (~59 w/o Pu-239 and ~11 w/o Pu-241).

Although about 96.5 w/o of SF comprises U and Pu which contain significant fractions of fissile isotopes, if SF is not to be reprocessed in order to recover U and Pu in it, it is classified as HLW, due to its high activity. In this case, the nuclear fuel cycle is named "Once-Through Cycle" (OTC) or open cycle. In OTC, after necessary (yet temporary) storage periods, SF is planned to be directly disposed of in a permanent disposal facility (waste repository).

U and Pu in SF can be recovered by reprocessing, in which a solvent extraction method called Purex is employed. In the standard reprocessing (SR), U and Pu in SF are obtained as pure and separate streams. U product of SR, after re-enrichment to a proper level and fabrication, can be re-introduced into the same reactor as fuel. Pu product of SR, after being blended with a fertile makeup (natural or depleted U) and fabricated into mixed U + Pu oxide (MOX) fuel, can also be irradiated in the same reactor. By recycling U and Pu in SF, up to 40% reduction in fresh fuel requirements can be achieved. Such a cycle in which U and Pu in SF are recovered and recycled is called the standard "Closed Cycle" (CC). During reprocessing, fission products and other actinides are obtained as a separate, barren stream and defined as HLW. After vitrification, vitrified HLW (VHLW) is planned to be disposed of in a permanent disposal facility (waste repository).

The final (permanent) disposal method widely accepted for SF/VHLW is the geological disposal. In geological disposal, canisters containing SF/VHLW are simply placed into boreholes in a geological formation deep underground, specifically selected for final disposal of nuclear wastes. The geological formation should be stable and deep enough to avoid surface events and to prevent accidental or intentional access to wastes in the long run.

1.2. Waste types

In case of OTC, the material to be disposed of is SF rods in canisters, denoted in this context as SUOX (Spent Uranium OXide).

* Corresponding author. Tel.: +90 312 295 8865; fax: +90 312 295 8957.
E-mail address: banubulut.acar@taek.gov.tr (B. Bulut Acar).

0306-4549/$ - see front matter © 2013 Elsevier Ltd. All rights reserved.
http://dx.doi.org/10.1016/j.anucene.2013.04.039

In case of CC, during reprocessing, the HLW solution containing fission products and other actinides is obtained; it is then glassified to form vitrified HLW (VHLW). VHLW is one of the waste forms to be considered in CC. In addition, recycle U (RcU) and MOX, after being re-irradiated in the reactor, are removed as spent RcU (SRcU) and spent MOX (SMOX). Since multiple recycling is not considered, SRcU and SMOX are categorized as waste and are sent to the final disposal. Note that the radioactive materials (cladding hulls, other fuel assembly structural materials, etc.) generated during the disassembling and chop-leach processes of the reprocessing in CC are not taken into account. Although these materials are generated in significant amounts, they are usually classified as Intermediate Level Waste, because they vary, to a considerable extent, in radiactivity level and chemical composition from the constituents of spent fuel.

Then, the waste types to be taken into account are: SF (SUOX, SMOX, SRcU) and VHLW. Note that, because decay heat profile of SRcU is not significantly different from that of SUOX, SRcU is not considered as a different waste type, and included in SUOX. To sum it up, the waste types under consideration are SUOX, SMOX and VHLW.

1.3. About burnup

Since composition and decay heat of any waste type are dependent on burnup, to observe the effect of burnup on waste disposal, computations are performed for a few selected burnup values: 33,000 (the reference), 40,000 and 50,000 MWd/tHM (Heavy Metal). Note that in case of OTC, there is only one burnup (discharge burnup of SF) value affecting the waste composition and decay heat. In case of CC, not only burnup of SF, but also burnup of recycle fuels (SRcU and SMOX) affect the waste contents and decay heat. To simplify the analysis in case of CC, it is assumed that burnups of SF and recycle fuels are the same. For example, when the specified burnup is, say, 40,000 MWd/tHM, what is meant is both the burnup of SF from which U, Pu and VHLW are extracted and the burnup to which RcU and MOX are burned are 40,000 MWd/tHM.

1.4. Reference repository and waste packages

The UK HLW/SF repository (Nirex Ltd., 2005) based on the KBS-3 concept, developed by SKB (Swedish Nuclear Fuel and Waste Company) for SF in Sweden, is taken as the reference repository. In the reference disposal concept, SF or VHLW is placed into copper canisters with a cast iron insert. The canisters are surrounded by bentonite buffer and placed vertically into holes excavated along parallel tunnels at a depth of 500 m in granite rock. Disposal tunnels will be backfilled with a mixture of bentonite and crushed rock after emplacement. Fig. 1 shows the UK HLW/SF repository concept.

Two different copper canisters are used for SF and VHLW. A SF canister is 4.5 m long and 0.9 m in diameter and contains four SUOX assemblies or one SMOX assembly. A VHLW canister is 3.2 m long and 0.9 m in diameter and contains two stainless steel cylinders loaded with VHLW. Each stainless steel cylinder is 0.43 m in diameter and 1.34 m long. It is assumed that each VHLW cylinder is loaded with 150 l VHLW bearing 10 w/o waste. SF and HLW disposal canisters are illustrated in Fig. 2.

The depths of deposition holes for SF and VHLW canisters are 7.55 and 6.25 m, respectively and the diameter of each hole is 1.75 m. The diameter of the disposal tunnel is 5.5 m. The distance between the disposal tunnels is 40 m (Nirex Ltd., 2005).

1.5. Outline of calculations

For the waste types, with different burnups selected, canister spacings and disposal areas per canister and per unit mass of waste are obtained first. Then, for OTC and CC, total amounts of waste types produced and total disposal areas required per unit mass of fresh fuel loaded into the reactor are calculated. Finally, results are converted to "total electrical energy (MWe-yr) produced per unit waste disposal area (m^2)" for OTC and CC. This is taken as the conclusive parameter to compare the two fuel cycles with regard to waste disposal density (area).

2. Procedure and computational tools

The computational flow chart is given in Fig. 3. The computational procedure has 2 major parts: (1) determination of composition and decay heat, which is done utilizing the code MONTEBURNS 2.0 (Poston and Trellue, 1999); and (2) determination of disposal area (or density) through thermal analysis, which is done using the code ANSYS (Ansys Inc., 2009).

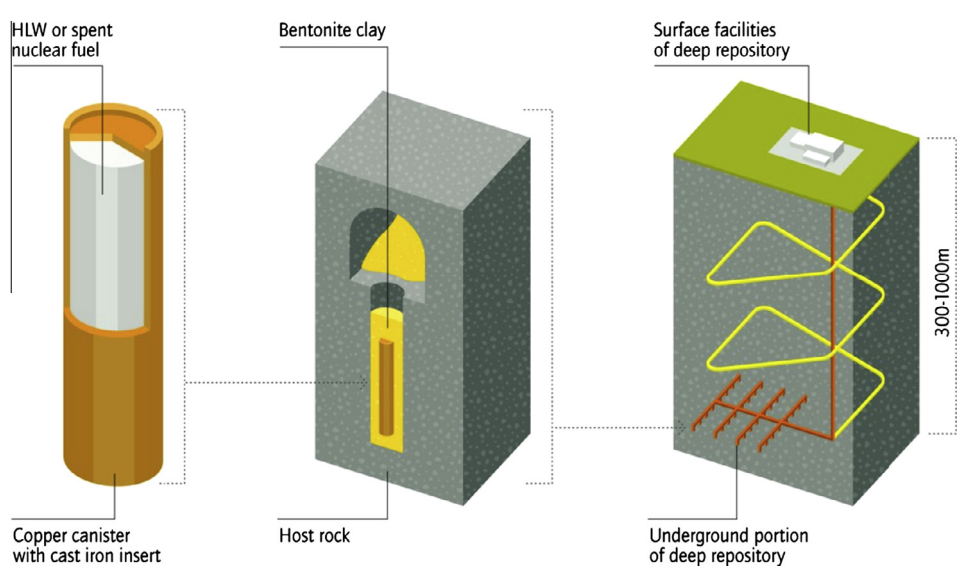

Fig. 1. UK HLW/SF repository concept (Nirex Ltd., 2005).

Download English Version:

https://daneshyari.com/en/article/8070115

Download Persian Version:

https://daneshyari.com/article/8070115

Daneshyari.com