Investigation of novel spent fuel verification system for safeguard application

Haneol Lee[a] and Man-Sung Yim[a*]
[a] *Department of Nuclear and Quantum Engineering, KAIST 291 Daehak-ro, Yuseong-gu, Daejeon, 34141, Republic of Korea*
[*]*Corresponding author: msyim@kaist.ac.kr*

1. Introduction

Radioactive waste, especially spent fuel, is generated from the operation of nuclear power plants. The final stage of radioactive waste management is disposal which isolates radioactive waste from the accessible environment and allows it to decay. The safety, security, and safeguard of a spent fuel repository have to be evaluated before its operation. Many researchers have evaluated the safety of a repository [1-3]. These researchers calculated dose to public after the repository is closed depending on their scenario.

Because most spent fuel repositories are non-retrievable, research on security or safeguards of spent fuel repositories have to be performed. Design based security or safeguard have to be developed for future repository designs. This study summarizes the requirements of future spent fuel repositories especially safeguards, and suggests a novel system which meets the safeguard requirements.

2. Spent fuel safeguard requirements

Traditional objective of IAEA safeguards is the "timely detection of diversion of significant quantities of nuclear material from peaceful nuclear material from peaceful activities to the manufacture of nuclear weapons or other nuclear explosive devices or for purposes unknown, and deterrence of such diversion by the risk of early detection" [4] and "to provide credible assurance of the absence of undeclared nuclear materials and activities in a State" [5].

The safeguard for a permanent disposal site cannot meet IAEA standards because the current safeguard concept assumes a retrievable repository as a repository type. Additional safeguard concepts should be developed for operating non-retrievable/permanent disposal facilities. Safeguard challenges identified by a closed expert meeting of IAEA, Application of Safeguards to Repository (ASTOR), for a permanent disposal site are [6]:

1. Verification of spent fuel at an encapsulation plant prior to transport and emplacement.
2. Unique identification of canisters at encapsulation plants.
3. Assuring that the canisters are emplaced as declared.
4. Assuring that no canisters are diverted before or after emplacement, including by excavating a closed and sealed repository.
5. Detecting such diversion or attempts in a timely manner.
6. Maintaining continuity of knowledge (CoK) about waste/spent fuel destined for disposal and after disposal.
7. Verifying repository design information through remote sensing methods and underground mapping which include construction and emplacement operation monitoring.
8. Applying effective containment and surveillance (C/S) measures to canisters and to the entire repository.
9. Implementing effective safeguard by design (SBD).
10. Maintaining safeguards in backfilled and closed repositories.

An electricity conversion system using spent fuel radiation which was studied by Lee and Yim [7] can be used to meet some of the advanced safeguard requirements related to spent fuel verification and surveillance. Safeguard requirements 1, 2, and 9 can be met using an electricity conversion system and safeguard requirements 3, 5, and 7 are may be met using the technology in the future.

3. Spent fuel verification system

3.1. Methods used for spent fuel verification system

Developing an index which characterizes spent fuel is needed to verify spent fuel. It is performed using Cerenkov radiation detector [8]. The Cerenkov radiation detector estimates the burnup and storage time of spent fuel using the burnup/storage time – intensity function depicted in Figure 1. To verify spent fuel using Cerenkov radiation detector, additional interim storage period in a cooling pool is needed.

The goal of this study is to develop an optimized spent fuel verification system which have shorter inspection time and higher security level. This study adopted an electricity conversion method using spent fuel radiation because the radiation from spent fuel is a function of burnup and storage time. The reason of detecting generated electricity instead of spent fuel radiation is because it is self-sustainable and self-reliance system which does not requires external power source or battery.

There are a number of methods to generate electricity using spent fuel radiation. The electricity conversion system using spent fuel radiation in this study adopted scintillator coupled with photovoltaic cell design. The conversion method follows two steps. The first step converts gamma ray and neutron from spent fuel into visible photons via scintillator. The second step generates electricity using scintillated photons entering photovoltaic cell.

This method was adopted because it can be operated while spent fuel is being processed. Other methods, such as radioisotope thermoelectric method or radiation battery, cannot be used because temperature difference is small and charged particle cannot penetrate spent fuel structure material. The method was validated in lab scale in the literature [7, 9, 10].

3.2. Design Concept of spent fuel verification system

The IAEA suggests the first safeguard requirement can be met using a Cerenkov radiation detector in the spent fuel storage pool of an encapsulation plant. It detects the intensity of Cerenkov radiation from a storage pool and estimates the burnup and storage time of the fuel which is depicted in Figure 1 [8]. The verification system using Cerenkov radiation can be replaced by electricity conversion systems which detect generated current and estimate the burnup/storage time of the spent fuel. This system makes the inspection time shorter because it can be implemented while the spent fuel is being transported in the encapsulation plant. The design is depicted in Figure 2. The verification system measures generated electric current and voltage while spent fuel assemblies are transported inside an encapsulation plant. The database for 'generated electricity-burnup/storage time' have to be established to safeguard nuclear material using an electricity conversion system.

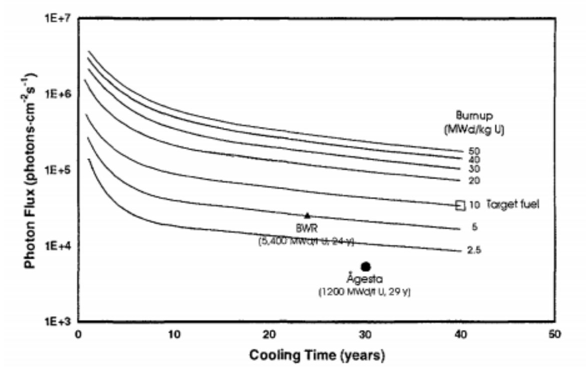

Fig. 1. Plots of Cerenkov photon flux as a function of spent fuel burnup and cooling [8].

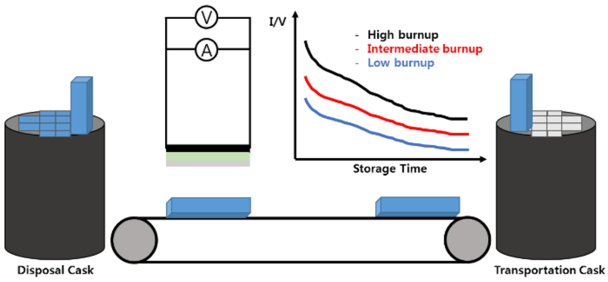

Fig. 2. Application of an electricity conversion system to an encapsulation plant.

There are technologies under development to meet safeguard requirement. It requires an identification tag inside a canister using magnetic based technology. If an electricity conversion system with an identification sensor attached inside the lid of a canister, is used it can continuously generate an identification signal from inside a transportation/disposal canister. Once the canister is located near a receptor, operators are able to record information about the nuclear material in the canister. The design concept of canister information reading system using an electricity conversion system is shown in Figure 3. The tag in Figure 3 includes an encrypted identifier, which contains information of nuclear material inside the canister.

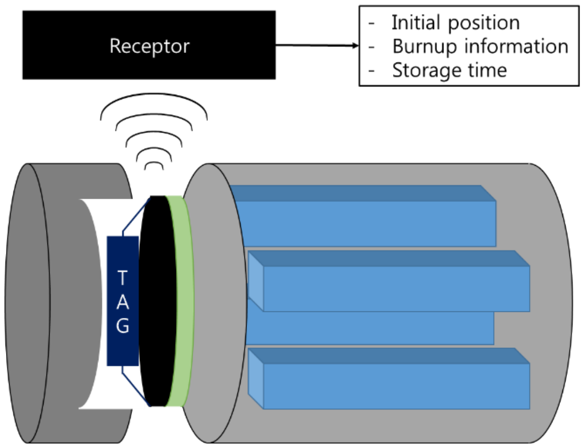

Fig. 3. Conceptual applying encrypted identifier to a disposal canister.

Because the safeguard systems applied above are considered "designed concepts", it meets the ninth safeguard requirement "Safeguard by design (SBD)". Future studies will demonstrate the feasibility and further application of electricity conversion system to remaining safeguard requirements.

4. Conclusions

Applying safeguards to a spent fuel repository is becoming increasingly important. The future requirements for a spent fuel repository are suggested by several expert groups, such as ASTOR in IAEA. The requirements emphasizes surveillance and verification.

The surveillance and verification of spent fuel is currently accomplished by using the Cerenkov radiation detector while spent fuel is being stored in a fuel pool.

This research investigated an advanced spent fuel verification system using a system which converts spent fuel radiation into electricity. The system generates electricity while it is conveyed from a transportation cask to a disposal cask. The electricity conversion system was verified in a lab scale experiment using an 8.51GBq Cs-137 gamma source.

Future studies include the relationship between spent fuel burnup/storage time and generated electricity. In addition, studies will address electricity conversion system validation in an extreme radiation environment, using a high activity radiation source.

REFERENCES

[1] L. Moreno and I. Neretnieks, Fluid flow and solute transport in a network of channels. Journal of Contaminant Hydrology, Vol. 14, pp. 163-192, 1993.

[2] J. Ahn, S. Kuo, ARelease of Radionuclides from Multiple Canisters in a High Level Waste Repository, UC Berkeley, UCB-NE-4221, 1998.

[3] C-. K. Park, et al., Preliminary Modeling for Solute Transport in a Fractured Zone at the Korea Underground Research Tunnel (KURT), Nuclear Engineering and Technology, Vol. 44, No. 1, 2011.

[4] IAEA, The Structure and Content of Agreements between the Agency and States Required in Connection with the Treaty on the Non-Proliferation of Nuclear Weapons, IAEA, INFCIRC/153, 1972.

[5] IAEA, Model Protocol Additional to the Agreements between State and the International Atomic Energy Agency for the Application of Safeguards, IAEA, INFCIRC/540, 1998.

[6] R. Haddal, et al., Geological Repository Safeguards: Options for the Future, Sandia National Laboratories, IAEA-CN-220-xx.

[7] H. Lee and M-. S. Yim, Examination of Spent Fuel Radiation Energy Conversion for Electricity Generation, Nuclear Engineering and Design, Vol. 300, pp. 384-392, 2016.

[8] J. D. Chen et al., Long-Cooled Spent Fuel Verification using a Digital Cerenkov Viewing Device, IAEA-SM-367/14/07.

[9] N. Horiuchi et al., Proposal of Utilization of Nuclear Spent Fuels for Gamma Cells, Solar Energy Materials & Solar Cells, Vol. 87, pp. 287-297, 2005.

[10] J. White et al., Novel Nuclear Powered Photocatalytic Energy Conversion, University of Messachusetts Lowell, DE-FG07-04ID14603, 2005.