Fissile Measurement in Waste Minimizing Fuel Process using Neutron Resonance

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ABSTRACT

Nuclear fissile material was measured at the waste produced in the waste minimizing fuel process, using neutron resonance technique. The waste has different material composition, shapes and characteristics at each stage in the process. Simulation was basically performed on U235 and Pu239 assay. The resonance energies were evaluated for uranium and plutonium for the hull waste and the linearity in detection response was examined by changing density for application of various type of wastes. The linear resonance energies were determined for content analysis of U235 and Pu239. From the simulation results, neutron resonance technique is promising to analyze U235 and Pu239 for waste material. Real time and non-destructive fissile assay plays an important role for large scale pyro-process. An accurate fissile assay will also contribute to an increased safeguards for the processing system in reuse of fissile materials.

INTRODUCTION

The technology for waste minimizing fuel process (in the pyro-process) is under development at KAERI (Korea Atomic Energy Research Institute), for obtaining a TRU product that will be used to fabricate fuel rods for the SFR (sodium fast reactor) and alleviating an environmental burden in high level waste storage. Nuclear waste is produced in the entire process[1]. Each waste has a different material composition, different radiation properties and shapes[1]. The waste is mainly classified into hull waste as a metal, salt waste in the process, and waste in the fabrication of a fuel rod at the final stage[1]. The hull waste has same property of spent fuel, but the content of fissile material is relatively small.

In the entire process, chemical analysis (DA) is basically determined for the analysis of nuclear material for safeguards[1]. However, if a non-destructive analysis (NDA) has enough analytic capability, it will be very helpful and powerful in the analysis of fissile material for large scale waste stream, as a complementary way. An uncertainty of nuclear material in the process wastes will be reduced by a combination of DA and NDA.

Several non-destructive technologies were evaluated[2,3], and applicable methods were simulated for the nuclear material assay in the nuclear waste, based on the direct discrimination of uranium and plutonium signals. A neutron resonance transmission technique is one option to analyze isotopic fissile content in waste[4,5,6]. The advantage of the neutron transmission technique is that a measured signal can be discriminated between isotopic uranium and plutonium, and a direct reaction with fissile isotopes is possible[4,6]. However, an intense neutron source is required for actual application on the fissile assay of the process nuclear waste. In the simulation, the resonance energies for U235 and Pu239 were evaluated and determined for waste assay, and the linearity in measurement was examined by changing the fissile content as well. The neutron measurement in resonances for uranium and plutonium has a direct correlation with the content of the isotopic fissile materials.

WASTE PRODUCTION

The major process and the production of waste in the process are summarized in Figure 1[1]. Generally, metal waste is produced from the dismantlement of a spent fuel assembly, recovery of fuel pellets, cutting process in the head-end process and fuel fabrication in the TRU-RE stage. Salt waste is mainly produced in the electro refining and winning process. In addition, a drawdown process has been under development to retrieve more remaining nuclear material in the waste.

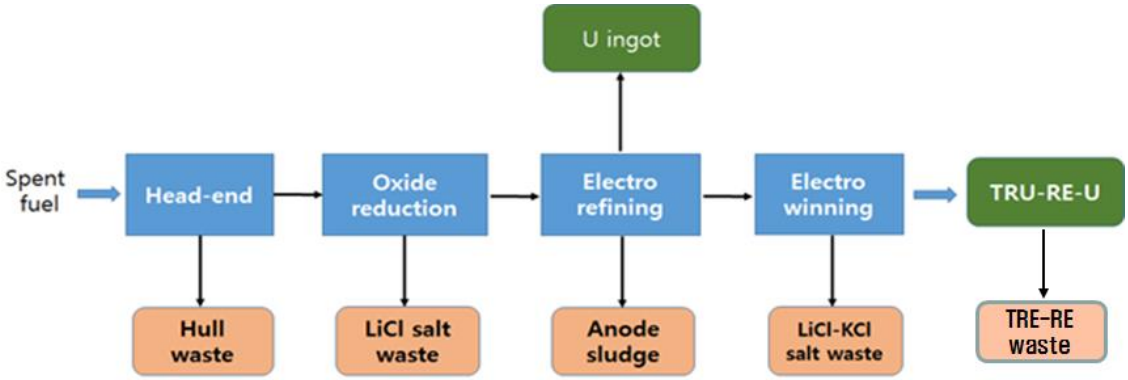


Fig. 1. Major waste production in the process stream.

The hull includes uranium, fission products, and TRU materials, such as spent fuel. The material composition depends on the burnup history and cooling time[7]. The property is the same as that of spent fuel. In SR (LiCl and LiCl-KCl) waste, nuclear material does not exist theoretically. For the RE salt waste, minor actinide including plutonium and curium are expected to be involved. Therefore, plutonium is required to be accounted for in waste for the control of the nuclear material of the process.

HULL WASTE MEASUREMENT

The hull has relatively small content of fissile. However, there are still intense radiation backgrounds which has a restriction on direct assay of isotopic fissile. Plutonium has more production at pellet surface by capture reaction of thermalized neutron. Therefore, the content of plutonium at cladding has almost same property as pellet surface. Uranium and plutonium isotopes exist at cladding and fissile content is required to be accounted. The content of fissile materials in hull is also important to balance fissile materials in the process[1]. For hull measurement, Cm244 emits intense spontaneous fission neutron as a background. Therefore, in the measurement, the transmission technique is required to obtain proper resonance energies for direct signal from U235 and Pu239[7].

In the transmission measurement[8], the sample composition was decided; isotopes of uranium, TRU materials and several fission products (Gd, Sm, Dy, Nd, Pr, Ce, La, Y)[7]. The fissile content was fixed same as in the spent fuel[7]. The sample volume (1x1x1cm) was selected and the detector size was 1inch in diameter with 2inch long. The simulation was performed on sample density change, from 0.1 to 12g/cc. The fissile content was assumed to be uniformly distributed in the sample volume. The transmitted signal was examined under 50eV which has sensitive resonances for U235 and Pu239, and relatively less sensitive for fission products. Figure 2 shows the measured signal with respect to neutron energies at different sample density. As shown in figure 2, the resonance structure was well shown at uranium and plutonium resonances. As the density increases, the resonance structure becomes clear. Above 1g/cc in sample density, all resonance structures are well defined in all neutron energies. The transmission depends on the sample density in hull waste.

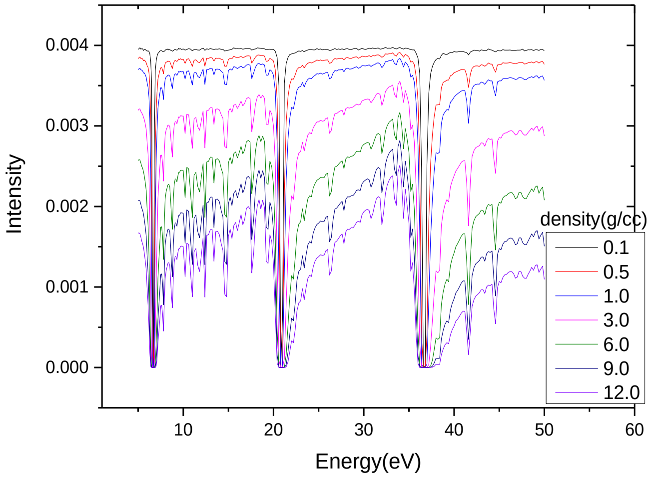
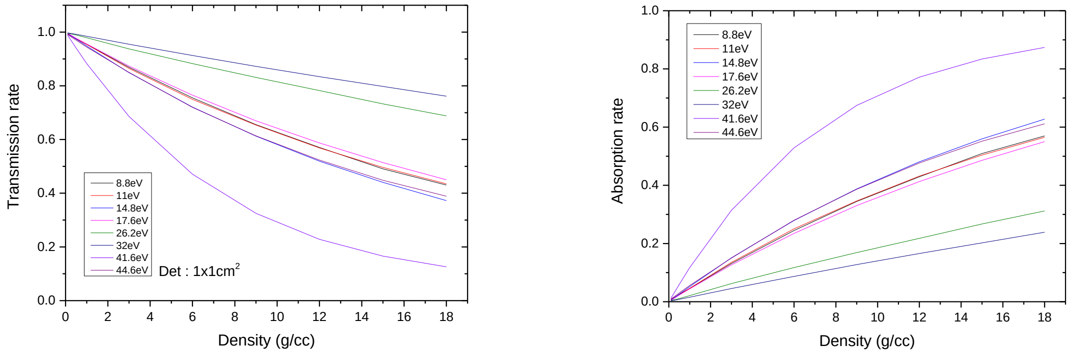


Fig. 2. Transmission property in hull with respect to the density change.

The prominent neutron energies were determined for uranium and plutonium. The neutron transmitted and absorbed rate was obtained at the selected resonance energies, for different sample density. Figure 3 shows the neutron transmission and absorption rate with respect to the density change. The results show that linear response was obtained at the energy of 26.2eV and 32eV for Pu239 and U235 in all densities. The selected energies can be utilized for the assay of Pu239 and U235 content in spent fuel hull and fissile wastes.



a) transmission b) absorption

Fig. 3. Transmission and absorption in hull with respect to the density change.

RESULTS AND CONCLUSION

The simulated measurement was basically examined on the direct signal discrimination for plutonium and uranium. The possibility of neutron resonance technique was examined for hull waste, as a supplementary way to obtain a cost-effective and time-saving approach in the fissile analysis. Uranium and plutonium isotopes have distinguished resonance properties. Neutron transmission technique has advantage to discern detection signal for uranium and plutonium in mixture. In the sensitivity simulations for the different fissile contents, the prominent resonance energies were determined for U235 and Pu239, and the linearity by fissile content increase was obtained at the selected energies. From the results, neutron resonance technique is very direct, powerful, and applicable to assay isotopic fissile materials for the waste. The selected resonance energies could be applied for different types of nuclear materials. An accurate measurement of plutonium content in the processing will contribute to international nuclear safeguards of the process facilities and reuse of fissile materials in a reactor, such as SFR.

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REFERENCES

1. S. Ahn, Preliminary conceptual design of safeguards system for KAPF, KAERI-TR6585, KAERI, 2016.
2. S. J. Tobin, Technical cross-cutting issues for the next geneartion safeguards intitiative’s spent fuel nondestructive assay project, Technical report, 2014.
3. M. Bolind, M. Seya, The State of the Art of the nondestructive assay of spent fuel assembly. JAEA2015-027, JAEA, 2015.
4. T. Hayakawa, Nondestructive assay of plutonium and minor actinide in spent fuel using nuclear resonance fluorescence with laser Compton scattering gamma rays, NIM A 621, 695, 2019.
5. J. Behrens, Neutron resonance transmission analysis of reactor fuel samples, Nuclear Technology, Vol 67, 1984.
6.] J. W. Sterbentz D. L. Chichester, INL/EXT-10-20620 Neutron Resonance Transmission Analysis (NRTA): A Nondestructive Assay Technique for the Next Generation Safeguards Initiative’s Plutonium Assay Challenge, Idaho 83415, 2010.
7. A. G. Croff, ORIGEN2 Isotope generation and depletion code matrix exponential method, Oak Ridge National Laboratory, 1985.
8. PELOWITZ, D., MCNPX user’s manual, LA-CP-05-0369, Los Alamos national laboratory, Los Alamos, 2005.