RERTR 2022 – 42ND INTERNATIONAL MEETING ON
REDUCED ENRICHMENT FOR RESEARCH AND TEST REACTORS

OCTOBER 3-5, 2022
VIENNA INTERNATIONAL CENTRE
VIENNA, AUSTRIA

Subcritical Experiment using U-7Mo LEU at KUCA facility

Yoshiyuki Takahashi[1),2)], Koki Wakabayashi[2)], Yasunori Kitamura[1),2)],
Hironobu Unesaki[1),2)] and Tsuyoshi Misawa[1),2)]

1) Institute for Integrated Nuclear and Radiation Science, Kyoto University (KURNS),
Kumatori-cho, Sennan-gun, Osaka 590-0494, Japan

2) Graduate School of Energy Science, Kyoto University
Sakyo-ku, Kyoto, Kyoto 606-8501, Japan

ABSTRACT

This paper summarizes the result of the first subcritical experiment using U-7Mo LEU fuel at the KUCA facility of Institute for Integrated Nuclear and Radiation Science, Kyoto University. The U-7Mo Al dispersion type LEU fuel used in this study is in form of 2" x 2" square coupon, fabricated at CERCA Romans plant as the sample coupons for the forthcoming KUCA conversion and utilized the identical design specification for the KUCA LEU coupon fuel. The U-7Mo LEU sample coupon was loaded into the natural uranium subcritical pile constructed in the KUCA facility (reactor room), and neutronic characteristics including neutron flux distribution and subcriticality index based on neutron noise analysis were measured. This experiment is the first series of the reactor physics experiment conducted using U-7Mo LEU fuel.

1 Introduction

Kyoto University Critical Assembly (KUCA) is currently underway of reactor conversion from HEU to LEU [1]. The conversion project has been officially initiated following the US-Japan joint announcement at 2016 Nuclear Security Summit, and both HEU return and LEU conversion studies has been conducted as an international cooperation between US and Japan. The LEU conversion itself has been on discussion since well before the 2016 NSS announcement, where feasibility study on the core characteristics of LEU loaded KUCA cores been conducted by ANL and KU to seek for optimal design of the LEU fuel. Based on the results of this feasibility study, KU has determined to introduce two types of LEU fuel to KUCA – e.g. U_3Si_2-Al dispersion type for "Wet core" and U7Mo-Al dispersion type for "Dry core"– to further enhance the experimental capability at KUCA and at the same time to initiate the neutronic study on U-7Mo fuel to support the forthcoming conversion science of high-performance research reactors.

The choice of U7Mo-Al dispersion fuel required extensive neutronics study of the converted KUCA core [2] as well as significant technology development challenges in fuel fabrication to realize the first-of-a-kind fuel to be used in a critical assembly. This technology development has been fully supported by USDOE/NNSA and CERCA (Framatome) has succeeded to develop an innovative fuel fabrication scheme at their Romans site [3][4]. Through this fuel fabrication technology development project, U7Mo-Al dispersion LEU sample (test) coupons as shown in Figure 1 (outer dimension of Al casing 2"x2"x 2.3mm, fuel meat thickness 0.45mm) were fabricated to demonstrate the fuel fabrication technology and also to verify fuel design specifications to meet the design requirements to proceed to the fabrication of the LEU reactor fuel.

The U7Mo LEU sample coupons are currently being transferred to KUCA to be used as test nuclear materials at the KUCA facility (e.g. not as reactor fuel). This paper summarizes the results of the first series of the subcritical experiment conducted.

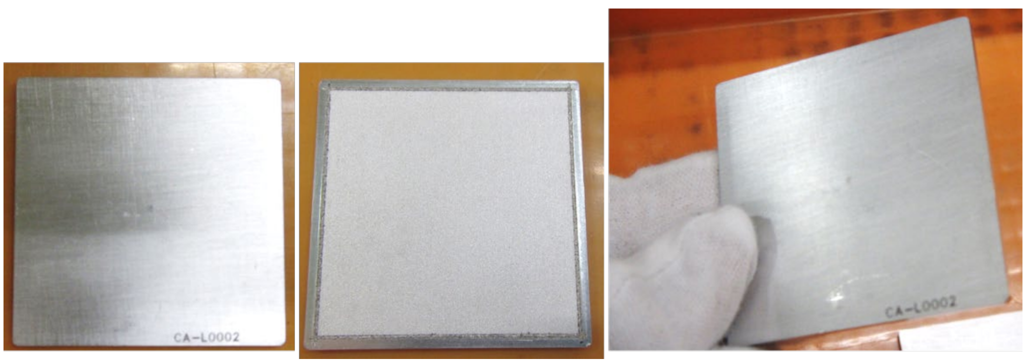

Figure 1. U7Mo-Al dispersion LEU sample coupon

2 Subcritical Experiment – setup

Subcritical pile, consisting of natural uranium (NU) and polyethylene, was constructed at the basement of KUCA facility reactor room. The NU element consists of 48 unit cells, where one NU metal plate (t=1mm) and two 1/8" polyethylene plates (t=3.175mm) are combined to form a unit cell. The basic configuration of the subcritical pile consists of 36 NU elements, surrounded by polyethylene reflector elements. The keff value for the basic configuration obtained by MCNP calculation is approximately 0.482.

For the present LEU experiment, one of the NU elements is replaced by a test zone element, consisting of test zone - 10 repetitions of test cell consisting of one Al plate (dimension identical to LEU sample coupons) and three 1/8" Polyethylene plates, sandwiched by upper and lower NU zone. The subcritical pile for the LEU experiment is shown in Fig. 2. The NU and test zone elements are shown in Fig. 3.

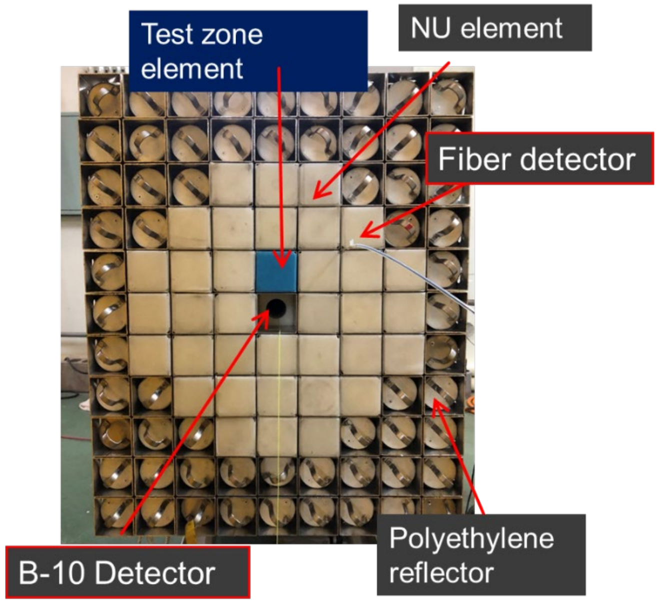

Figure 2. Subcritical pile for the LEU experiment

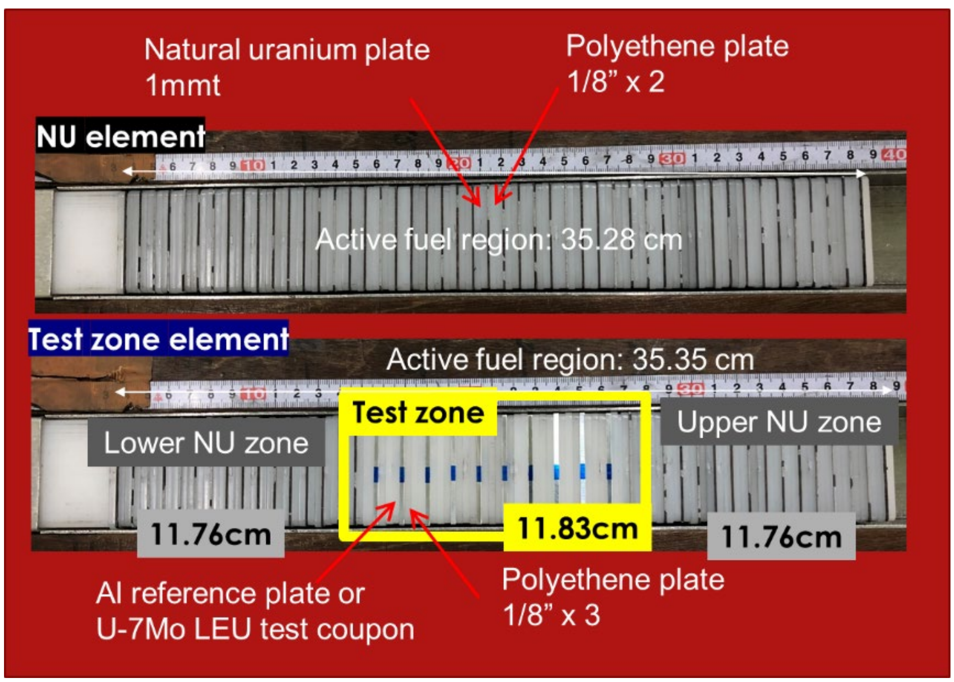

Figure 3. NU and test zone element

The LEU sample coupons were loaded in the test zone element by substituting the Al reference plates with LEU sample coupons as shown in Figure 4. The test zone element with LEU sample coupon has been loaded into the subcritical pile, and neutron detectors (B-10 for neutron noise measurement, optical fiber detector for neutron flux distribution measurement) were inserted to the pile as shown in Figure 5.

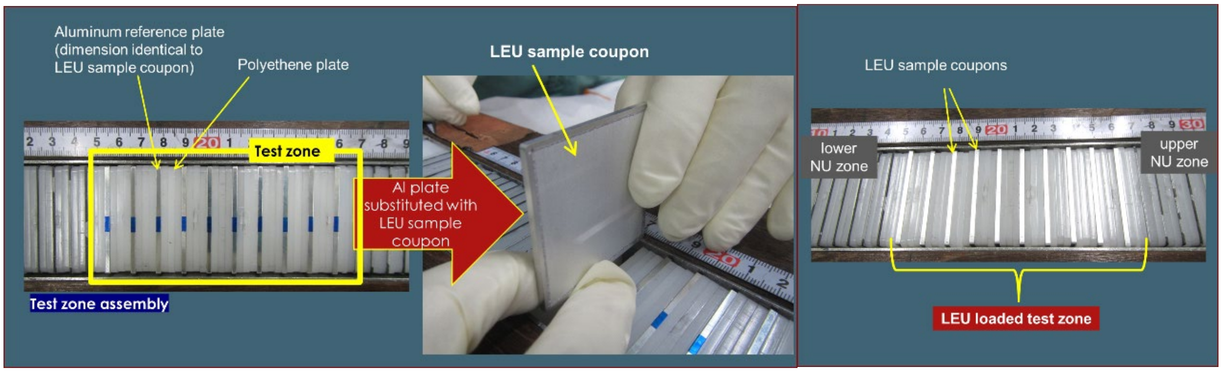

Figure 4. Loading of LEU sample coupons in test zone

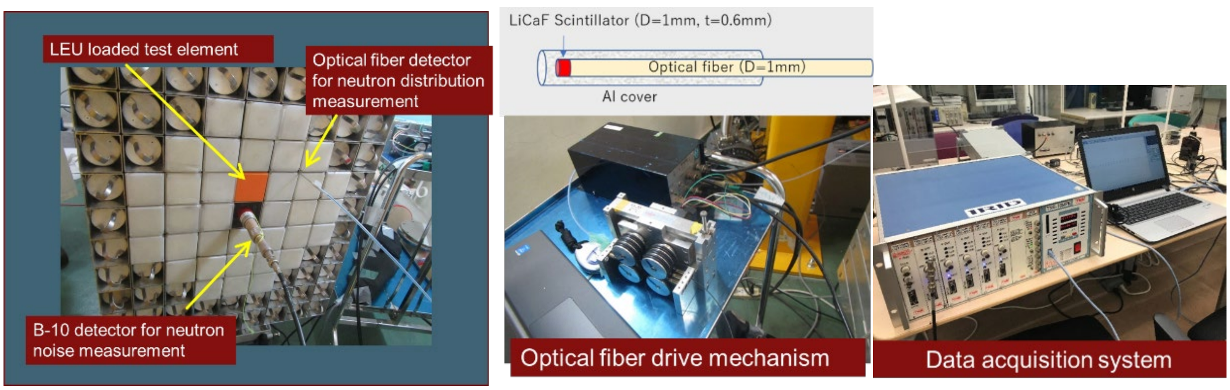

Figure 5. LEU loaded subcritical pile and experimental setups

The detector signals from both B-10 and optical fiber detectors [5] were accumulated as time stamp data (e.g. each detected event recorded as time stamp data with time resolution of 1 micro second) using dedicated MCA system.

For the neutron noise experiment, no external neutron source was used; spontaneous fission neutron from U-238 has been utilized as neutron source to induce fission chain reaction in the subcritical pile.

The optical fiber detector is driven by using a dedicated fiber drive mechanism, and the corresponding position of the detector head (LiCaF scintillator) has been also recorded by the data accumulation system to convert the time stamp data to position-dependent data. During the optical fiber detector experiment, the B-10 detector at the core center has been removed, and an external neutron source (^{252}Cf) has been inserted in the mid-core position.

3 Subcritical Experiment – first results and discussions

3.1 Neutron Noise Experiment

The time series data from B-10 neutron detector are processed to generate neutron pulse signal train and then analyzed using Feynman-a method based on data bunching method [6] with deadtime correction and finite time series length correction. In the first analysis, two major parameters obtained from Feynman-α analysis – e.g. α value (delayed neutron fraction over neutron lifetime) and Yinf (limit of Y-value) – were compared. Figure 6 shows the preliminary results of Feynman-α analysis, which shows the decrease of a value and increase of Yinf value for the LEU loaded subcritical pile, indicating the positive reactivity effect caused by the LEU addition. The detailed behavior of the Y-value shows some notable difference between Al reference and LEU loaded cases, which shall be further confirmed by the further addition of LEU into the subcritical pile.

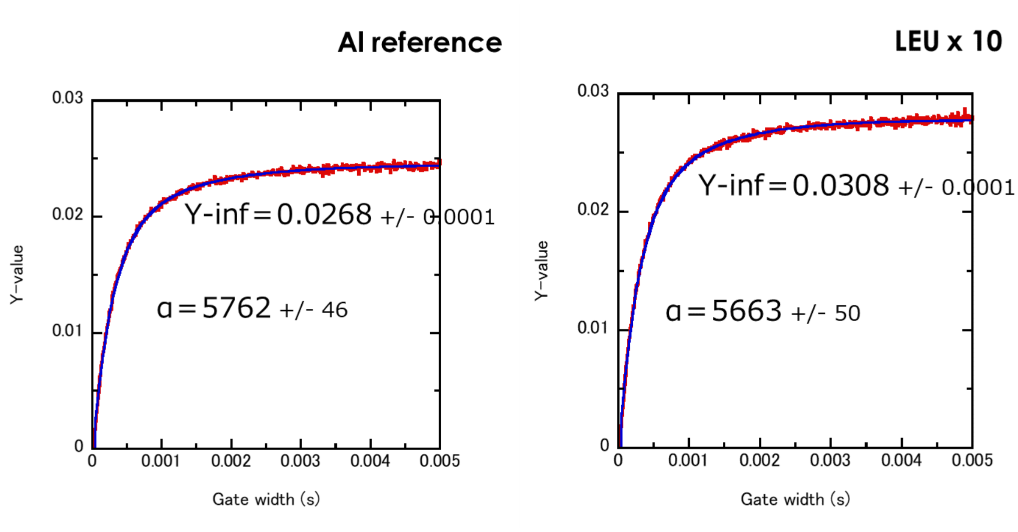

Figure 6. Result of neutron noise experiment (Feynman-α analysis)

3.2 Neutron Flux Distribution Measurement

The time series data from LiCaF scintillator optical fiber detector are processed to obtain the spatial distribution of neutron flux (or more precisely, as Li-6 capture reaction rate) along the horizontal axis of the subcritical pile. Neutron flux distribution results for Al reference case and LEU loaded case are shown in Figure 7, where the overall increase in the neutron count rate could be observed. The neutron flux at the test region also show significant peak for the LEU loaded case, indicating the increase in neutron multiplication by the introduction of the LEU sample coupons.

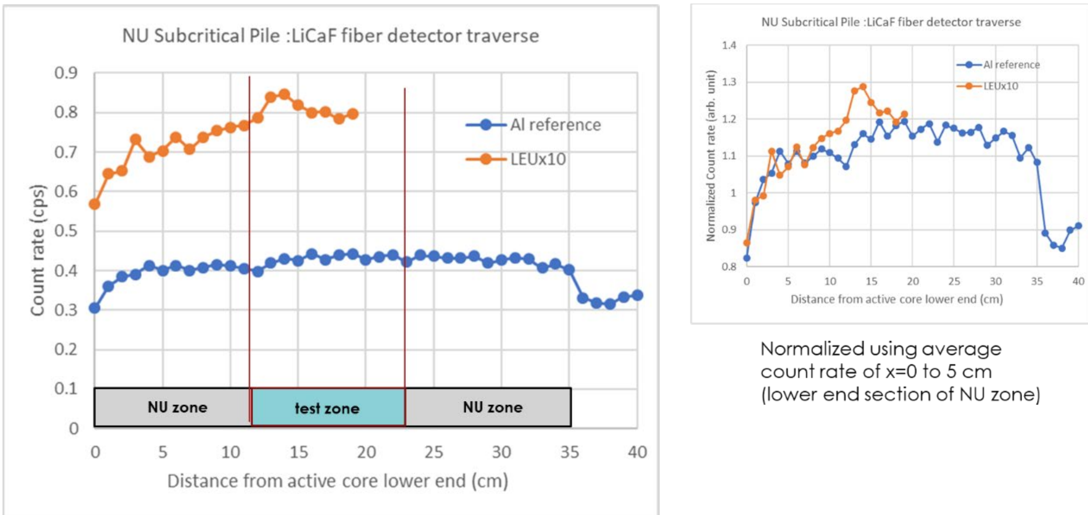

Figure 7. Result of neutron flux distribution (Li-6 reaction rate distribution)

4 Conclusion and future works

The LEU loaded subcritical experiments presented in this paper could be considered as the first reactor physics experiment on U-7Mo LEU fuel. Although the presented results are of preliminary nature, the impact of U-7Mo LEU fuel in terms of reactivity (subcriticality) has been clearly observed, and the results are subject to further analysis in terms of data processing and comparison with calculation to understand the underlying reactor physics.

The authors are planning to extend the experiment using more LEU sample coupons to expand the LEU loaded zone and also to change the hydrogen-to-Uranium ratio in the test zone by changing the combination of LEU sample coupon and polyethylene plates. These series of extended experiments are expected to provide systematic information on the neutronic behavior of U7Mo-Al dispersion fuel and hopefully contribute to conversion technology improvement for high-performance reactor.

Acknowledgements

The authors would like to acknowledge the continuous effort and support of the KUCA conversion project team members of USDOE/NNSA, Argonne National Laboratory, Framatome/CERCA and Sojitsu Machinery Co. Ltd. The authors would like to take this opportunity to acknowledge the continuous support from MEXT, Japan on the KUCA conversion project.

References

[1] H. Unesaki, T. Misawa, Y. Takahashi, B. Stepnik, J. Allenou, C. Rontard, D. Geslin, J.G. Stevens, J.A. Morman, G. Alberti, J.M. Park, J. Dickerson, B. Waud, “KUCA Conversion Project - Challenges and Achievements”, Proc. International Conference on Nuclear Security, February 10-14, 2020, IAEA, Vienna, Austria (2020).

[2] G. Aliberti, J.A. Morman, J.G. Stevens, T. Sano, H. Unesaki, T. Misawa, B. Stepnik, "Update of Neutronic Analysis of KUCA Dry Core using LEU Fuel", Proc. European Research Reactor Conference RRFM 2018 (2018).

[3] B. Stepnik et al., " Preliminary manufacturing studies of the KUCA LEU conversion fuels", RERTR 2017 – 38th International Meeting on Reduced Enrichment for Research and Test Reactors, November 12-15, 2017, Chicago, IL, USA (2017).

[4] J. Allenou et al., " Preliminary Uranium Manufacturing Studies of the KUCA LEU Conversion Fuels", RERTR 2018 – 39th International Meeting on Reduced Enrichment for Research and Test Reactors, November 4-7, 2018, Edinburgh, Scotland (2018).

[5] C. Mori, K. Kageyama, Y. Mito, K. Yanagida, A. Uritani, H. Miyahara, Y. Wu, K. Kobayashi, C. Ichihara, S. Shiroya, M. Hayashi, H. Unesaki, I. Kimura, T. Iguchi and M. Nakazawa, "Development of Neutron and Gamma-Ray Flux Distribution Measurement System with Scintillator and Optical Fiber Combination", *Reactor Dosimetry* (2001).

[6] Y. Kitamura, T. Misawa, H. Unesaki and S. Shiroya, "General Formulae for the Feynman-alpha Method with the Bunching Technique", Annals of Nucl. Energy, Vol. 27, No. 13, pp.1199-1216 (2000).