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Development of a Neutron Multiplicity Counter System for the Nuclear Material Accounting and Safeguards in KAERI

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A well-type neutron multiplicity counter(WNMC) system was installed in a hot cell for the purpose of nuclear material control, accounting (NMC&A) and safeguards. The WNMC system determined the nuclear material amount on the basis of the Cm-monitoring method by measuring the neutron multiplicity and the number of coincidence events. The developed system consisted of 20 He-3 tubes with a 2.54 cm diameter and 50 cm length to cover a 25 cm long uniform neutron efficiency region along the tube length direction. As a neutron moderator in order to increase the neutron absorption rate at the He-3 tube, a well type high density polyethylene(HDPE) with a 50cm diameter was used. The efficiently optimized cylindrical Cd-plate was used in order to satisfy the uniformity along the tube direction. The absolute neutron detection efficiency of the HDPE system was measured about 14.0 % and the die-away time was 51.6μs. This system will be used not only for NMC&A but also the process for material quality control, for example, decladding performance of rod-cuts and the homogeneity of a mixing powder, waste and ingot.

KEY WORDS: Well-type, Neutron multiplicity counter, Nuclear material accounting, Safeguards, Spent fuel

I. Introduction

A safeguards system based on the neutron inventory verification method in the dry process for the reuse of nuclear spent fuels was introduced to account for the nuclear materials in the whole process by selectively measuring the spontaneous fission neutrons from ^{244}Cm. One of the dry process is the DUPIC(Direct Use of Spent PWR Fuel in CANDU Reactors) process which is to produce CANDU-type fuel directly out of spent PWR fuel material with no alternation to the composition of the spent fuel throughout the whole process. The characteristics of the DUPIC process could be summarized as no separation of the process material, difficulty of a direct access to the material due to a high radiation level, and the remote operation of the fuel fabrication behind heavy shields [1,2].

For this purpose, a well-type neutron multiplicity counter system with substantial shielding to protect the system from the high gamma radiation of the spent fuel was installed to measure the amount of curium in the fuel bundle and the associated process samples in the process.

II. Nuclear material accounting and control principle

For safeguards implementation KAERI and LANL have been jointly pursuing the development of an appropriate nuclear material verification system by introducing neutron coincidence measurement technology [3,4,5]. **Fig. 1** is the MC&A(material control & accounting) concept on the basis of the neutron non-destructive analysis method.

The major sources of neutron in the spent fuel at shut down are ^{238,240,242}Pu and ^{242,244}Cm. However, the relative composition of these isotopes varies with cooling time and after a few years cooling ^{244}Cm becomes the dominant source of the neutron. All other isotopes are about 2 orders of magnitude lower than ^{244}Cm when the burn-up (BU) is higher than ~25 GWd/tU and the cooling time is over ~3 years [6].

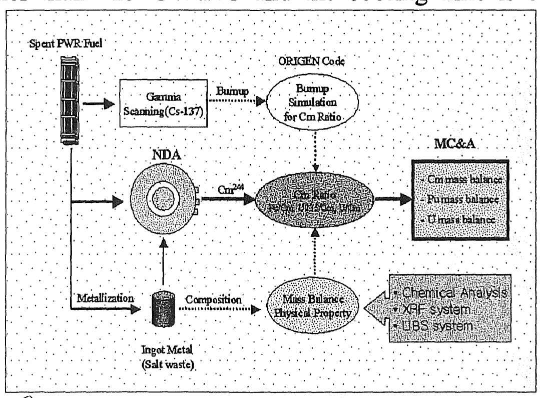

Fig. 1 Nuclear material accounting flow concept

The ^{244}Cm mass in the spent fuel could be extracted by measuring the coincident neutron rate(doubles rate). The doubles rate, R, is in proportion to the ^{244}Cm mass in spent fuel sample with a relation of

$$m_{Cm} = k * R_{Cm}$$

where k is a constant which should include a small multiplication correction in the doubles rate for the UO_2 in the rods and pellets. It is determined by using ^{252}Cf standard sources, and then checked by counting three other standard spent fuel reference rods in the hot cell.

To determine the Pu mass in the spent fuel the Cm-ratio, defined as the relative mass ratio between the Pu and Cm, should be predetermined. The Cm-ratio is determined indirectly by combining the results of Cs-137 burn-up measurement and the ORIGEN-2 code calculation, and

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crosschecked by a chemical analysis for the spent fuel sample.

III. Design of the WNMC system

The NDA system must satisfy the following requirements: 1) NDA system should be a radiation hard system, so it dose not contain any weak material for radiation, especially gamma rays. 2) The assay chamber can be measured for a bundle which has a diameter of 10 cm and a length of 25 cm. Therefore, the neutron efficiency must be uniform for at least 25 cm along the He-3 tube.

The conceptual drawing of manufactured the WNMC is shown in **Fig. 2**. WNMC is a well-type neutron coincidence counter. It consists of 20 He-3 tubes with a 2.54 cm diameter, 50 cm active length and 4-atm of pressurized He-3 gas. The He-3 tubes were located concentrically in the high density polyethylene moderator for the purpose of the neutron energy degradation to obtain an adequate detection efficiency.

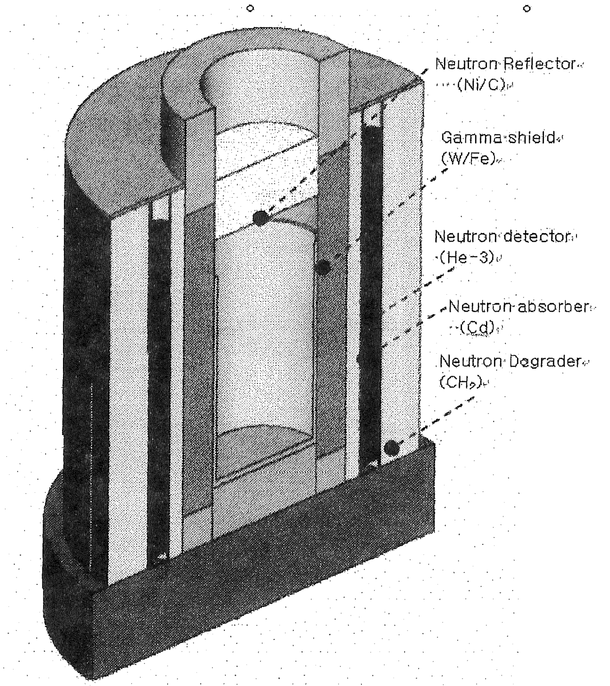

Fig. 2 Schematic drawing of NWMC system

Each of He-3 tubes are directly attached to PDT-110A modules which contain a preamplifier, amplifier and discriminator to generate TTL signals for the arrival time of the neutrons. A preamplifier status lamp was cabled to each tube in order to monitor the visual states of the operation in the hot cell. The noise could be rejected by setting the discrimination level of amplification gain to give approximately the same LED blink rate in the detector cavity. Each of the 4 amplifiers will be grouped to provide diagnostic information as well as the capability to reduce the counting rate in the shift register. In order to remotely operate the WNMC in the hot-cell, long cables of high voltage bias, amplifier power supply, and signals will be connected to a AMSR(Advanced Multiplicity Shift Register) located outside hot-cell. To maintain a stable and uniform preamplifier power, a +5V regulator will be installed at the input stage of WNMC.

A cylindrical gamma-ray shield will be installed around the central cavity to protect the He-3 tube and electronics from the intense gamma-rays of a maximum surface dose of $\sim 10^4$ R/h for the process material [5].

WNMC was designed in such a way that all types of process material are measurable (bundle, powder, rod-cut, hulls, and wastes) to spare space in the hot cell during the lab scale operation. One way of achieving this goal is to maintain a constant detection efficiency along the axial direction of the He-3 tubes. Normally both ends of a neutron counter gives lower detection efficiencies compared to its middle position. In order to flatten the longitudinal detection efficiency, neutron reflectors were mounted at both ends(nickel for bottom and graphite for top) and various sizes of the cadmium strip was attached individually on the face of the 50 cm long He-3 tube directed towards the center of the WNMC.(**Fig. 3**)

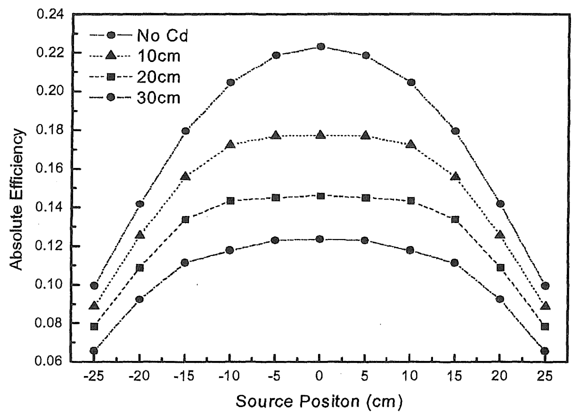

Fig. 3. The Longitudinal detection efficiency MCNP calculation with respect to Cd-plate length

Two types of NDA models were considered. One is 30 cm in length for the He-3 tube and the other is 50 cm. The major consideration for the MCNP simulation is that the proposed the specification could keep the uniform neutron detection efficiency along He-3 tube at least 25cm. The MCNP simulation using the 50 cm He tube with a cylindrical shape Cd absorber with a 20 cm length showed a uniform detection efficiency over 20 cm length as shown in **Fig. 3**. In order to expand it to over 25 cm for the uniform efficiency region, several kinds of neutron reflectors will be inserted.

IV. Experiment and discussion

The WNMC system was manufactured except for the gamma shield. The NWMC consisted of 20 He-3 tubes with a 2.54 cm diameter, high density polyethylene as a neutron degrader, and cylindrical Cd-plate asa neutron absorber.

The neutron detection efficiency was measured as a function of the high voltage bias as shown in **Fig. 4**. It was saturated above 1,800V. The optimum bias voltage was determined as 1,850V at the G-M region.

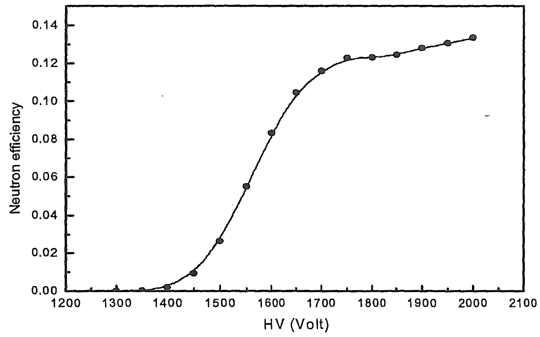

Fig. 4 Detection efficiency as a function of the bias voltage

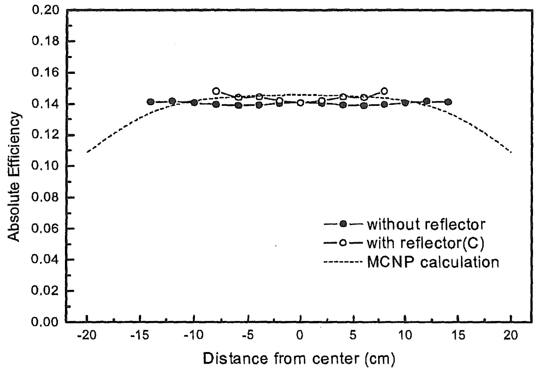

Fig. 5 Measurement result for 50 cm of the He-3 tube system.

Figure .5 is the preliminary result for the optimization using the 50 cm long He-3 tube. Without a reflector the WNMC system showed 14.0 % of absolute neutron detection efficiency. The longitudinal detection efficiency distribution at every position including both ends was measured to be less than a 0.6 % deviation from the average value along 30 cm of the He-3 tube in the longitudinal direction. The neutron detection efficiency of this system turned out to be larger than the previously developed WNMC, called DSNC [4,5]

This system is well optimized without a reflector. If a reflector was adopted in this system, then the detection efficiency is expected to be increased. As shown in **Fig. 5**, the inserted graphite reflectors at the upper and bottom sides functioned to increase the detection efficiency near the edges of He-3 tubes by reuse of the reflected neutron. Therefore, reflector is a useful component to increase neutron detection efficiency near bottom region. The next study will be focused on satisfying the uniform neutron efficiency over 25 cm using a reflector component.

Neutron multiplicity distribution of the WNMC system was measured by AMSR as shown in **Fig. 6**, and compared with the result of the MCNP-X calculation. Multiplicity is defined as the number of neutrons captured at the detectors within a given gate width of 64 μs which covers the die-away time. The measured die-away time was 51.6μs by using an exponential decay tendency of the Rossi-Alpha distribution which is the time between the correlated events.

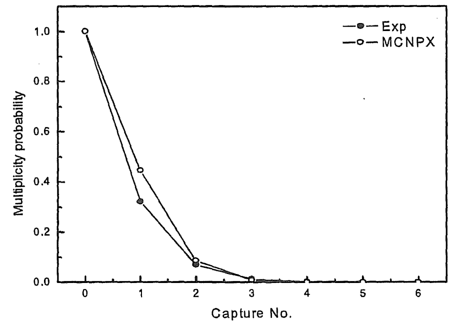

Fig. 6 Multiplicity distribution simulation using MCNP-X

V. Conclusion

A well-type neutron multiplicity counter system is useful equipment for the purpose of nuclear material control, accounting and safeguards for a high dose radiation environment where the gamma-ray method dose not available.

The developed WNMC system shows good agreement with the design requirements as a result of the prototype system experiment. This system will be used not only for NMC&A but also process material quality control.

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