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# INSTRUMENT DEVELOPMENT FOR SAFEGUARDS IMPLEMENTATION ON SPENT CANDU FUELS IN KOREA

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## ABSTRACT

Korea is operating four CANDU reactors since the first in 1980 and is planning to have two more in the future. Safeguards implementation on CANDU reactors is complex and requires more safeguards efforts. Three safeguards instruments were developed recently to conduct national inspection on CANDU reactors. They are SCAV (Spent CANDU Fuel Verifier) for verifying spent fuel inventory in the storage pool, SCAI (Spent CANDU Fuel Bundle Serial Number Identifier) for reading serial number of spent fuel bundle in the pool, and SCAD (Spent CANDU Fuel Finger-Printer at Dry Storage) for dry storage inventory verification. These instruments were field tested, performed well, and are being used in inspection.

## INTRODUCTION

Korea has been carrying out national safeguards inspection since 1997. The subject of national safeguards inspection is the Ministry of Science and Technology (MOST). Technology Center for Nuclear Control (TCNC) of the Korea Atomic Energy Research Institute (KAERI) supports MOST by implementing safeguards and conducting related technical developments.

Since the first national inspection, CANDU reactors among targets under safeguards have been considered more important due to their complexities. About half of safeguards inspection efforts goes to CANDU reactors even though number of CANDU is smaller than that of LWR. According to facility attachments, PDIs (Person Day Inspections) of CANDU reactor is about three times higher than that of LWR.

A unique character of CANDU reactor is its on loading fuel. It means that every day some fresh fuels are loaded to reactor core and some fuels are discharged from core to spent fuel storage pond. Its inherent nature of on-loading of fuels and its potential diversion has made IAEA pay more attention for verification than that of LWR. Besides verification on nuclear materials at reactor, in some countries like Argentina and Korea, safeguards inspection is also carried out on the spent fuel transfer campaign which takes place once or twice every year and lasts usually several months. In Korea, spent fuel transfer campaign moves old spent fuels, which are cooled over 7 years in spent fuel storage pond, to dry storage silos due to lack of storage space in pond. Spent fuel bundles have to be thoroughly managed under the IAEA and national safeguards criteria because it is classified as the direct nuclear materials by safeguards criteria. It requires substantial safeguards inspection efforts for international and national safeguards.

Three nondestructive instruments were developed by TCNC for use of national safeguards inspection, with consideration of potential common use with IAEA, at Wolsong nuclear power plants which are CANDU type reactors. The first is the Spent CANDU Fuel Verifier (SCAV) to measure gamma rays emitted from spent fuel bundles stored in spent fuel storage pond. The second instrument is the Spent CANDU Fuel Bundle Serial Number Identifier (SCAI) to identify spent fuel bundles by reading serial number inscribed on end-plate. The last one is the Spent CANDU Fuel Finger-printer at Dry Storage (SCAD) to verify gamma profile signature of spent fuel canisters stored at dry storage silo.

Figure 1 shows schematic flow of spent CANDU fuel from reactor to silo and the location of above mentioned safeguards instruments.

## SAFEGUARDS INSTRUMENTS

### Spent CANDU Fuel Verifier

SCAV (Spent CANDU Fuel Verifier) was made to verify spent fuel inventory stored in the storage pond by means of underwater gamma scanning device equipped with supporting and indexing frame, stepping motor and semiconductor radiation detector.

Spent CANDU fuel bundles are stacked in multi

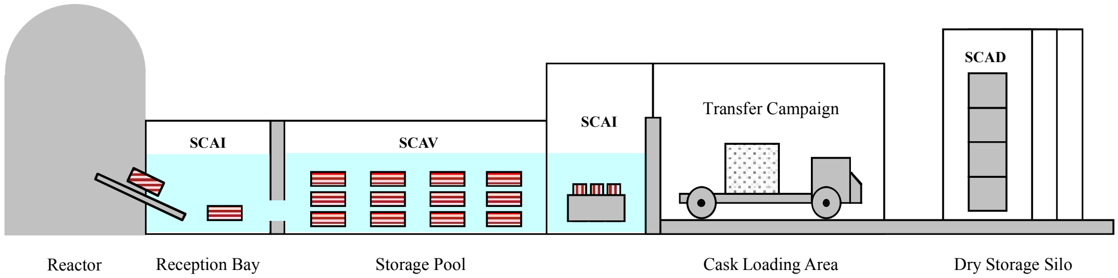


Fig. 1 Schematic Drawing of Spent CANDU Fuel Flow at Wolsong Nuclear Power Plant and Location of Developed Safeguards Instruments for National Inspection

layers on the rack horizontally, whereas spent LWR fuel assemblies vertically. Space between racks is fairly narrow which creates restriction on manipulation of verifying system. Mechanical system and sensors were designed and fabricated to get exact indexing of each bundle. Current SCAV is the second generation that was upgraded from the first SCAV.

Figure 2 shows a general layout of SCAV installed in one of spent fuel storage ponds at Wolsong nuclear power plants, which has the storage capacity of around forty thousand bundles, 7.7 meters as a nominal water depth and 2.8 meters as the height of 19 layers in the water.

Stationary frame of SCAV is held on the operator guard bar of the facility-gantry which moves above the pool area. Mobile frame can be moved vertically with a variable speed ranging from a few millimeter to several centimeter per second by stepping motor which is driven by a control unit equipped with a palm-top computer. Detector supporting tubes of mobile frame are assembled with several pipe nodes to match the water depth of storage pool. All mechanical parts except stepping motor, rack gear and detection head were made of aluminum material and their surface were coated for easy decontamination. All parts can be packed in a rigid case (1.7x0.4x0.3 m) and total system weighs some 80 kg. For gamma-ray measurement, a small pin type CdTe or CdZnTe semiconductor detector with radiation tolerant preamplifier in its housing is positioned at the central hollow of a detector head which consists of a cylindrical tungsten shield/collimator and stainless housing. Shield diameter is 90 mm or 110 mm (two types) and the collimating horizontal air-hole diameter is 7 mm.

Gamma-ray signals from the preamplifier are sent to a portable MCA (multi-channel analyzer) mounted on the rack of stationary frame. Figure 3 shows detection head part of SCAV and spent CANDU fuel bundles stacked in storage rack of pond.

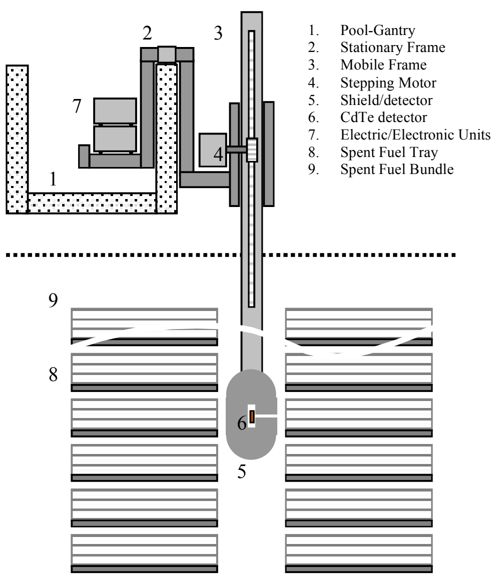


Fig. 2 Schematic Layout of SCAV Installed at Spent Fuel Storage Pool

Fig. 3 Photo of SCAV Detection Head and Spent CANDU Fuel Bundles in Storage Rack of Pool

The gap between tray layers shown in this figure, through which detector head moves downwards or upwards, is about 15 cm in width. This gap width restricts the increasing of shield thickness for the verification of short-cooled fuel bundles.

Figure 4 shows one of the inspection results performed at Wolsong unit 1 by using SCAV operated with scanning speed of 1.5 cm per second. In this figure solid circles denote the measured, background subtracted, gamma-ray intensities at different vertical positions and discrete peak-type lines are taken by smoothed second derivative[1~3] of the measured raw data for counting the number of inspected fuel bundles by software program. 19 peaks corresponding to the number of spent CANDU fuel bundles are found by auto search program in this figure. There is some difficulty to verify clearly when the bundles with very short cooling time (approximately less than 0.5 year) are stacked together or when the fuel with extremely low burn-up(about less than 1 GWD/MTU) is surrounded with fuel bundles with normal burn-up because high level background counting strongly disturbed the gamma-ray intensities collected through collimator. It seems that this problem could be partially solved by using a smaller detector and/or by upgrading the analyzing program. TCNC staffs are also improving the mechanical and electric/electronic parts for easy treatment at the spent fuel storage pond area.

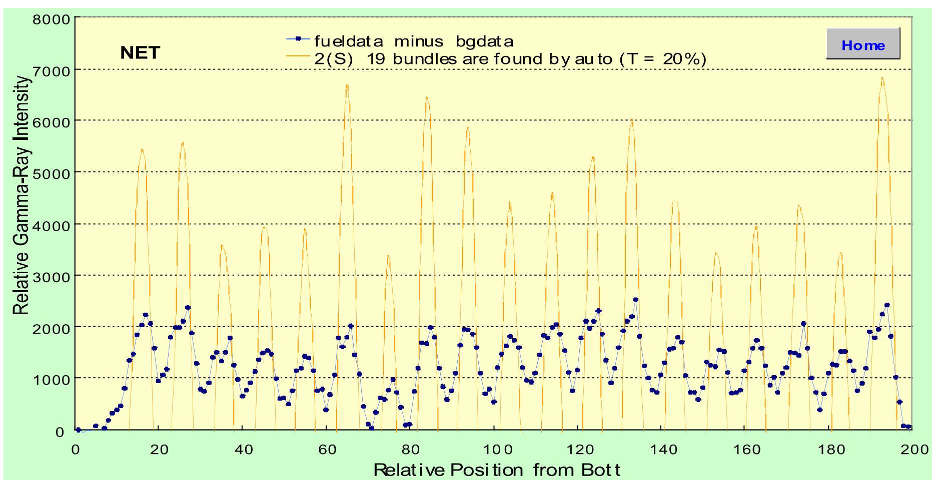


Fig. 4 An Example of Gamma-Scanning Results on Spent CANDU Fuels of Wolsong N.P.P. by SCAV

## Spent CANDU Fuel Bundle Serial Number Identifier

SCAI (Spent CANDU Fuel Bundle Serial Number Identifier) was developed to read serial numbers of spent fuel bundles loaded in the basket placed in the spent fuel storage pond and spent fuel bundles moving to tray in the reception bay after discharge from core. Spent CANDU fuel transfer campaign[4] has taken place for several months every year at Wolsong unit 1 under IAEA safeguards inspection since 1992.

During the spent fuel transfer campaign to dry storage silos, facility operators load 60 bundles from the tilt table to the basket placed on the underwater working table. Before operators place a cover onto basket, i.e. the nuclear materials in basket becomes difficult-to-access, inspectors confirm number of spent fuel bundles loaded in basket and randomly select and identify a few bundles per fully loaded basket. Operators move the covered basket to the welding station, weld the covered basket inside the transfer flask and ship the transfer flask with basket to dry storage silos. One of bottlenecks among safeguards inspection activities during the fuel transfer campaign is to identify spent fuel bundles because inspectors should read serial numbers inscribed with small size letters (about 20(W)x2(H) mm) which are usually faded by exposure in the core as well as lengthy storage in the pond over 7 years.

Figure 5 shows a schematic drawing of SCAI installed on the facility structure, which can effectively read serial numbers of spent fuel bundles loaded in the basket placed in the storage pond during the fuel transfer campaign. And also the serial numbers of spent fuel bundles discharged from core can be identified by using SCAI installed on the facility structure as shown in figure 6. SCAI consists of three main components as shown in figure 7. Underwater camera & light, that is water-tight and its permissible dose rate is $3x10^6$ rads $hr^{-1}$, can approach closely to the end-plate of spent fuel bundle and take a distinct picture of serial number. And as this camera has non-browning 8 to 24mm zoom lens, SCAI can take a picture of serial number with high resolution in the deep storage pond. Mechanical supporting frame & guide tube maintains underwater camera & light part closely to the end-plate of the selected spent fuel bundle without interfering fuel loading process. Controller & monitor is used to adjust the camera & light part to get optimized picture of serial number, and the image on monitor can be recorded by videotape recorder for its review and storage.

During the recent spent fuel transfer campaign at Wolsong unit 1, inspectors randomly selected 2 bundles per fully loaded basket and conducted the serial number identification by using SCAI. It was also used to read serial number of the spent fuel bundles moving to tray in the reception bay after discharge from the initial core of Wolsong unit 3. Figure 8 shows one of the results taken at Wolsong power plants. SCAI showed several advantages compared to the underwater optical periscope for international safeguards inspection. It can save substantial inspection time and efforts due to its easy indexing and handling, and fine picture. Major merit is to save workforce and related cost. It is inspector friendly because inspectors can easily assemble/disassemble the modularized SCAI, and also they can easily operate SCAI after several practices in the storage pond.

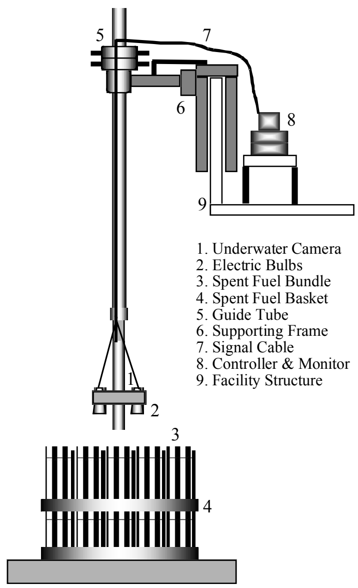


Fig. 5 SCAI Installed in Storage Pool

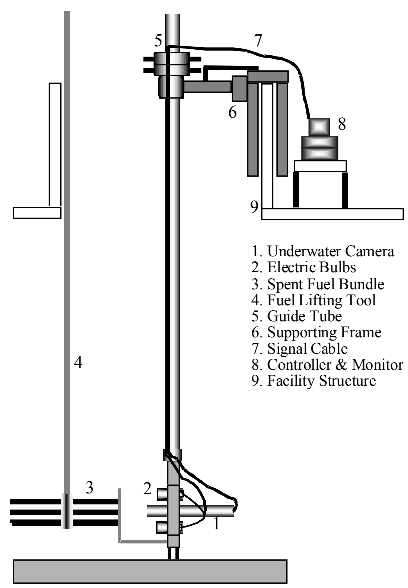


Fig. 6 SCAI Installed in Reception Bay

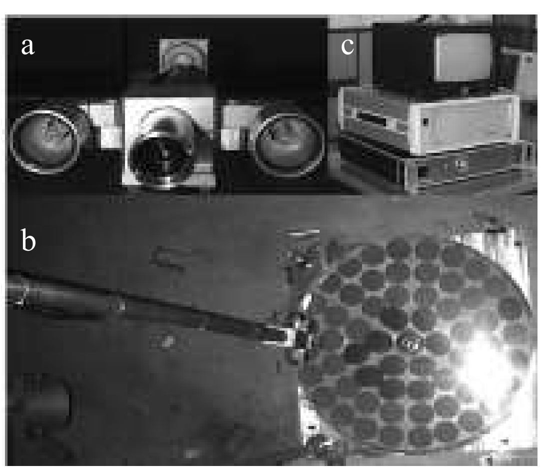


Fig. 7 Photo of SCAI Components
(a) Underwater Camera & Light
(b) Spent Fuel Basket & Guide Tube
(c) Controller & Monitor

Fig. 8 Serial Number of Spent CANDU Fuel Bundle Taken by SCAI in Storage Pool

### Spent CANDU Fuel Finger-Printer at Dry Storage

SCAD (Spent CANDU Fuel Finger-Printer at Dry Storage) was developed to verify the spent fuel inventory stored at dry canister (diameter:3.1m, height:6.5m) in Wolsong power plant. Spent CANDU fuel bundles cooled over 7 years in the spent fuel storage pool are transferred to dry storage silo that has storage capacity of 9 baskets (60 bundles in a basket).

A schematic layout of SCAD installed at dry storage silo is shown in figure 9. Figure 10 shows the photo of motor & detector holder and shielded detector head. Mechanical hardware part is setup upon the dry storage silo and the others such as PMCA, motor controller and notebook computer are located on ground basis.

A small pin-type CdTe or CdZnTe detector (diameter: 9mm, length: 80mm) encapsulated in a cylindrical tungsten shield (diameter: 30mm) is used as a radiation detector. A stepping motor and its controller is used for positioning and moving of detector inside the re-verification tube. Portable multi-channel analyzer (PMCA) and computer with software is used for data collection and evaluation.

Detector cable holder guides detector to move inside re-verification tube of dry storage silo by stepping motor driven by a motor controller connected with a notebook computer. Control and analysis software programmed by Lab windows/CVI controls PMCA and motor controller simultaneously or independently through the RS-232 communication port. Measured raw data are transferred to PC and saved automatically, and a spectrum displayed on a monitor is automatically analyzed.

Figure 11 shows one of inspection results, called as finger-print, at dry storage in Wolsong power plant by gross scanning method of SCAD. Scanning speed was about 5 cm per second and dwell time of multi-channel scaling mode of PMCA was set 1 second. Scanning direction was from bottom to top of dry storage silo. In this figure, 9 peaks corresponding to the number of baskets stocked in the silo are detected by treating the measured raw data by means of smoothed second derivative[1~3].

Currently SCAD is used as an effective instrument for re-verification as well as mother finger-print generation of dry canister for safeguards purpose. As next step, TCNC is trying to use Cs-137(662 keV) intensity distribution instead of gross gamma-ray intensity distribution as the finger-printer indicator because it can provide more evident signal of a specific position of spent fuels in the silo[5].

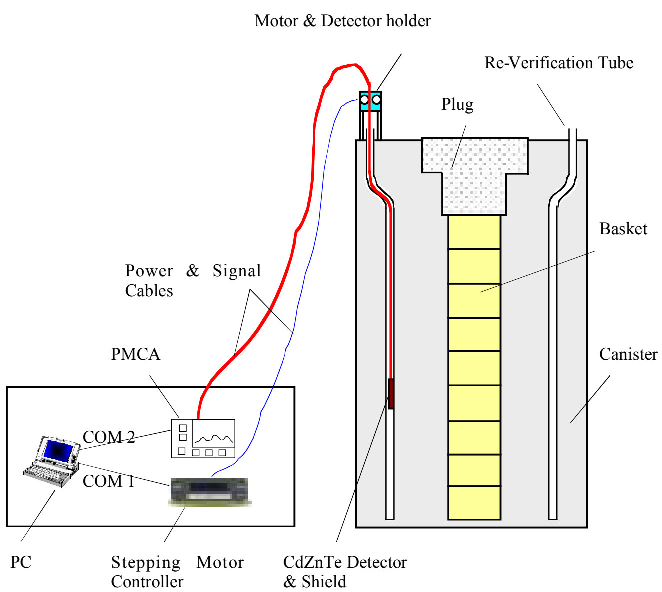


Fig. 9 Schematic Layout of SCAD at Dry Storage Silo

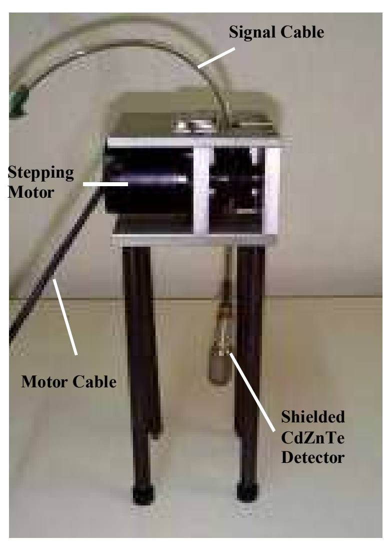


Fig. 10 Photo of SCAD Components

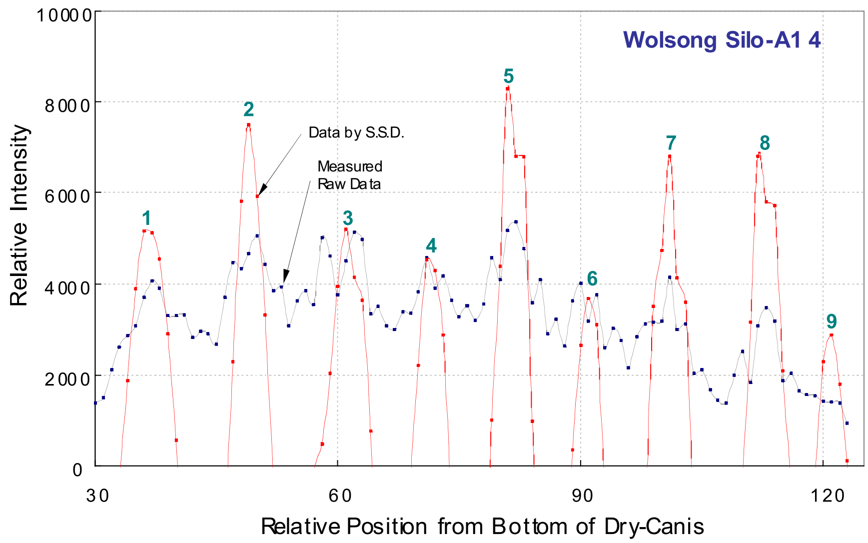


Fig. 11 An Example of Gross Gamma Scanning Results of Dry Storage Silo of Wolsong N.P.P. by SCAD

**CONCLUSION**

Since initiation of national safeguards inspection, TCNC has tried to reduce PDIs through careful analysis of process and procedures. Inspection on CANDU reactors is relatively complicated and it requires new inspection instruments to streamline process. Three passive NDA instruments have been developed, field tested and are under operation for national inspection. Based on developed NDA technologies and field experiences for safeguards implementation, TCNC will continuously put a lot of efforts in development of new instruments which can erase bottlenecks of safeguards inspection and increase safeguards efficiency.

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