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Life Evaluation of Spent Fuel Visual Inspection Camera (CCD)

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1. Introduction

To facilitate the dry storage of spent fuel, a procedure to assess the presence of defects in the fuel is crucial. According to NUREG-1536, storing defective fuel in dry storage casks can lead to an increase in internal pressure due to fission gases, potentially compromising the cask of the vessel and posing a potential radiological hazard by failing to fulfill the storage system's functions. Thus, the process of categorizing fuel based on the type of defect is of paramount importance.

In practice, nuclear power plants typically perform defect inspections (visual inspections) on spent fuel in the spent fuel pool during planned maintenance and outage periods. The essential component of the inspection equipment, the Charge-Coupled Device (CCD)[1] camera, is periodically replaced based on usage history.

Currently, to maintain the quality of inspection screens during visual inspections, CCD cameras are replaced every three outages during Operation and Maintenance (O&M) activities. However, a lack of technical justification exists for conducting a quantitative assessment of the CCD's life.

Therefore, this paper selects representative spent fuel assemblies and conducts replacement cycle and life assessments of CCD cameras based on dose limits in order to address this gap.

2. Methods and Results

2.1 Selection of Representative Fuel

In this radiation assessment, the selected fuel types for evaluation were the 17WH fuel and the 16CE fuel, with detailed conditions presented in Tables 2-1 and 2-2, respectively.

Table 2-1. Condition of the Representative Fuel(17WH)

Fuel Type	17WH	Burnup	50,000 / 60,000
Cycle	3	Distance	0.65 m
Cooltime	100hr	Enrichment	4.8 w/o

Table 2-2. Condition of the Representative Fuel(16CE)

Fuel Type	16CE	Burnup	50,000 / 60,000
Cycle	3	Distance	0.65 m
Cooltime	100hr	Enrichment	4.65 w/o

2.2 Radiation Evaluation

2.2.1 Source

The program used for the radiological assessment of representative fuel to obtain input data for CCD life evaluation is the ORIGEN-ARP module within the SCALE 6.1. From a radiation protection perspective, the radiological hazards that need to be considered are as follows:

○ Gamma Radiation
▸ Primary gamma rays from nuclear fission products and actinide decay
▸ Secondary gamma rays generated by neutron capture reactions of fissile and non-fissile materials

○ Neutron Radiation
▸ Neutrons emitted from spontaneous fission
▸ Neutrons emitted from reactions involving fuel materials

Among these, the influence of neutron sources and secondary gamma rays generated by neutron capture reactions has been excluded from this assessment. This exclusion is due to their values being relatively negligible compared to primary gamma radiation sources in this evaluation.

2.2.1 Flux

The emitted gamma-ray spectra from radioactive materials in the effective fuel region and structural components were evaluated using the ORIGEN-ARP module of the SCALE 6.1. The primary gamma-ray spectra resulting from fission products and decay were divided into 18 energy groups[2]. The combined values of arithmetic averages of burnup, enrichment, and other relevant parameters for each time interval were used in the assessment.

2.3 Evaluation of Radiation

The radiation assessment for the CCD (Charge-Coupled Device) life evaluation of spent fuel was conducted using MCNP6.1.

For the CCD life assessment of spent fuel, two evaluation models were simulated based on the previously described 17WH and 16CE fuel types. The assessment included the representative spent fuel, basket, and neutron absorber material in a comprehensive manner, encompassing the effective fuel region as well as upper and lower structural components.

The CCD was positioned in the evaluation model according to its technical specifications, with dimensions of 5 × 4.5 × 7.5 cm (width × height × depth), placed at the top, bottom, and center of the fuel assembly, to perform the assessment.

Figure 2-1. CCD Module

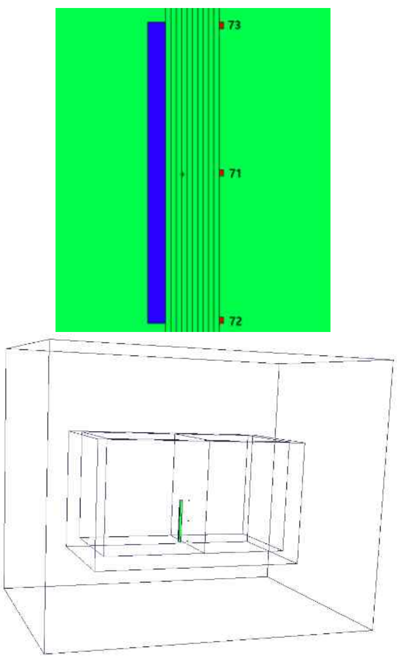

Figure 2-2. Modeling Geometry using MCNP 2D(up), 3D(down)

For the radiation assessment of the CCD life evaluation for spent fuel, a representative fuel assembly was chosen within the spent fuel pool, and a tally location was designated at a distance of 0.65 meters away from the fuel assembly.

For the evaluation, the MCNP code was employed, and an F6 Tally was utilized to calculate the absorbed dose in the CCD. The output unit of the F6 Tally was provided in MeV/g, and the absorbed dose was computed by converting it from MeV/g to the absorbed dose unit (Gy) as follows [3]:

$$Gy = (F6\ Tally\ \ output\ )\ x\,(\frac{Mev}{g})\ x\,(\frac{1.6\ x\,10^{-13}J}{Mev})\ x\ (\frac{1000g}{kg})$$

Furthermore, considering that 1 Gy = 100 rad, the absorbed dose was converted to the dose rate unit for this evaluation. Based on the aforementioned conditions, the CCD's radiation assessment was conducted.

The life of the visual inspection equipment's CCD was determined based on the radiation assessment submitted by the manufacturer (AHLBERG ELECTRONICS). According to the report provided by the manufacturer, the camera's performance was maintained up to a cumulative radiation dose of 25 Mrad. Therefore, the assessment was conducted using a life of 25 Mrad as the reference point.

Table 2-3. Result of Life Evaluation Submitted by Manufacturer[4]

No.	Dose Rate (rad/h)	Exposure time (h)	Acc. Dose (rad)	Image with internal lighting	Remarks
1	1 Mrad	5	5 Mrad	High quality	Clear image
2	1 Mrad	10	15 Mrad	High quality	Clear image
3	1 Mrad	10	25 Mrad	High quality	Clear image
4	1 Mrad	5	30 Mrad	Good quality	Dots in inmage
5	1 Mrad	5	35 Mrad	Bad quality	Lost color
6	1 Mrad	5	40 Mrad	Bad quality	Lost all functions

2.4 Results

The CCD life assessment results for the two types of fuel are presented in the following table.

Table 2-4-1. Result of 17WH Type Fuel
(4.8 w/o, 60,000 MWD/MTU, CT:100hr)

Fuel location	F6 tally output [Mev/g/s]	Dose [Gy/s]	Dose [Gy/hr]	Life Assessment [hr]
Top	1.41E+08	2.26E-02	8.13E+03	3076
Middle	**2.59E+08**	**4.14E**-02	**1.49E+04**	**1676**
Bottom	1.57E+08	2.51E-02	9.03E+03	2768

Table 2-4-2. Result of 17WH Type Fuel
(4.8 w/o, 50,000 MWD/MTU, CT:100hr)

Fuel location	F6 tally output [Mev/g/s]	Dose [Gy/s]	Dose [Gy/hr]	Life Assessment [hr]
Top	1.39E+08	2.23E-02	8.02E+03	3119
Middle	**2.52E+08**	**4.03E**-02	**1.45E+04**	**1725**
Bottom	1.52E+08	2.43E-02	8.75E+03	2856

Table 2-5-1. Result of 16CE Type Fuel
(4.8 w/o, 50,000 MWD/MTU, CT:100hr)

Fuel location	F6 tally output [Mev/g/s]	Dose [Gy/s]	Dose [Gy/hr]	Life Assessment [hr]
Top	9.75E+07	1.52E-02	5.62E+03	4452
Middle	**2.52E+08**	**4.04E**-02	**1.45E+04**	**1721**
Bottom	1.50E+08	2.40E-02	8.64E+03	2895

Table 2-5-2. Result of 16CE Type Fuel
(4.8 w/o, 50,000 MWD/MTU, CT:100hr)

Fuel location	F6 tally output [Mev/g/s]	Dose [Gy/s]	Dose [Gy/hr]	Life Assessment [hr]
Top	9.61E+07	1.54E-02	5.54E+03	3119
Middle	**2.49E+08**	**3.98E**-02	**1.43E+04**	**1725**
Bottom	1.46E+08	2.34E-02	8.43E+03	2856

3. Conclusions

This paper was conducted to evaluate the lifespan of a CCD in an optical inspection camera module for used nuclear fuel.

Two types of fuel were used, and the absorbed dose rate affecting the CCD was calculated during visual inspections conducted at a distance of 0.65 m from the fuel.

The calculated absorbed dose rates for the 17WH fuel were 1.49E+04 Gy/hr and 1.45E+04 Gy/hr, resulting in estimated lifespans of 1676 hours and 1721 hours for neutron fluences of 50,000 MWD/MTU and 60,000 MWD/MTU, respectively.

For the 16CE fuel, the calculated absorbed dose rates were 1.45E+04 Gy/hr and 1.43E+04 Gy/hr, leading to estimated lifespans of 1721 hours and 1725 hours for neutron fluences of 50,000 MWD/MTU and 60,000 MWD/MTU, respectively.

Based on these results, the data will be used to determine replacement cycles according to the dose rate limits for the CCD.

REFERENCES

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[4] AHLBERG ELECTRONICS, Radiation test report of alhberg Electronics HD camera module, camera housing and camera cable