LWR SPENT FUEL CASK REACTIVITY MEASUREMENT SYSTEM

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SUMMARY

As initial enrichment and burnup of fuel assemblies in nuclear power reactors increases, taking burnup credit is now proceeding in LWR spent fuel cask criticality safety design. This paper describes a reactivity measurement system based upon the passive neutron measurement technique in wet condition(PA-w system) developed to obtain a subcriticality value by making direct in-cask measurement of neutron flux.

The PA-w system comprises four sub-systems; the main control software, the computer analysis software, the data base and the on-site work. Analytical simulations, assuming nine PWR type fuel assemblies in a cask with a square array and four neutron detectors installed around the fuel assemblies, have been run to determine the system performance. The results demonstrated that the PA-w system is feasible for measuring the burnup of each loaded fuel assembly and the k-eff accurately, and has sufficient CPU time for fuel loading work.

INTRODUCTION

If measurements are required to take burnup credit, then it is necessary to measure the burnup or subcriticality of spent fuel assemblies. Although when compared with burnup monitors, keff measurements have had few applications to industrial use, it has the advantages of being able to monitor subcriticality directly for criticality safety control. This paper describes a new method, the PA-w system, which is able to lead both burnup and subcriticality at every step of loading spent fuel assemblies into a cask.

OUTLINE OF PA-w SYSTEM

PA-w system makes use of neutrons emitted from spent fuel assemblies as neutron source. The PA-w system's main process flow, as shown in Figure 1, is as follows:

- Neutron counting rate measurement is carried out at every step of loading spent fuel assemblies into a cask:
- Simultaneously, the computer code in the system calculates the neutron flux and k-eff

- based upon the information related to burnup, cooling time and the fuel type from the reactor records:
- The calculation results and the measured neutron counting rates are compared. If a large difference is observed, iterative calculations are carried out in the system software to modify burnup values:
- After spent fuel has been loaded to a cask, detailed k-eff calculations for the whole system are performed.

SYSTEM OVERALL STRUCTURE

The PA-w system comprises four sub-systems as shown in Figure 2 :

- the main control software which controls the whole system;
- the computer analysis software for calculating the neutron flux distribution and k-eff, and automatically inputting the data;
- the data base, including data processed in computer codes, and;
- the on-site work of handling neutron detectors and spent fuels.

The main control software ,as shown in Figure 2, plans the procedure for loading each fuel assembly into a cask, measures the correction factors for the neutron detectors counting rates using a neutron checking source, and monitors the burnup of each assembly and subcriticality at every step of loading spent fuel assemblies into a cask. The only additional on-site work required is the handling of the neutron detectors and a neutron calibration source. In the computer analysis software, input data of computer codes is provided automatically by indication from the main control software.

EQUIPMENTS

The system requires no additional equipment other than the neutron measurement system, the neutron calibration source handling system for neutron counting correction, and a computer system to run the associated software.

One or several neutron detectors are installed in a watertight insertion pipe. The pipes are inserted into a cask cavity before carrying the cask to the loading pit, as shown in Figure 3. The pipes are inserted near the surroundings or the corners of the fuel loading region of the cask basket. Because the operation is carried out in a high gamma environment, a fission counter is used as a detector. The associated electronics and data acquisition equipment is housed in a cabinet with casters by a pool.

SYSTEM PERFORMANCE

In order to investigate the performance of the system, some simulations were conducted based upon the assumption that nine PWR type fuel assemblies were put into a cask with a square array, and that four neutron detectors were installed around the fuel assemblies, as shown in Figure 4. The performance with which the system estimates the burnup of a spent fuel assembly loaded in the above square array model has been investigated. The typical counting rates response curves for each detector, which are shown in Figure 5, show that the detector for the fuel assemblies which are being loaded has high neutron count rates response. On the other hand, the response of the detector from which they are going far away is remarkably low. The PA-w system makes use of these characteristics to determine the order in which fuel assemblies are loaded and a detector for monitoring.

Two kinds of simulation analysis were conducted, one involving the usual small difference of burnup of 5 GWd/t between real and initial assumption for a blind assembly, the other involving a large burnup difference of 20 GWd/t, simulating an abnormal condition. Assemblies other than a blind assembly are assumed to be 40 GWd/t.

The results are shown in Table 1 which shows that this system's PA-w software has detected the burnup difference and has led the correct burnup by from 3 to 7 iterative calculations with a 1 to 2 % accuracy for burnup. The system's computer code can also calculate k-eff (neutron source multiplication ratio) based upon the above burnup information with low theoretical error rates.

SYSTEM ERRORS

The system errors are caused by ; the relative positions of assemblies and detectors, spent fuel burnup history errors, neutron count rate statistical errors, fuel composition errors, burnup fuels reactivity errors, and reactivity errors related to radial and axial burnup distributions.(DOE 1995), (Ewing et al. 1994), (Boyd et al. 1991)

The above has been investigated and the investigation results are summed up in Table 2. According to the results of Table 2, a large error can be caused by axial burnup distribution.

STUDY OF AXIAL BURNUP DISTRIBUTION

In general, axial burnup distributions for PWR spent fuels are described in Figure 6 and can be approximately expressed by the following equation for the edge region.

$$B(H,N) = Bo[\sin(H/60*\pi)]^{N} \qquad (1)$$

B : Burnup (GWd/t)
Bo : Burnup in the axial central region(GWd/t)
H : Fraction of full fuel length to distance from edge surface (%), ≦30
N : shape factor

In order to monitor axial burnup distributions, it is necessary to put more than 3 detectors into a detector pipe. The detectors other than the one in the center of the fuel region are positioned around the lower and upper fuel edges. Figure 7 showed the difference of the burnup between the assumption of 3D calculation and the results of X-Y 2D calculations based upon the count rates from 3D calculation. According to Figure 7, the detector positioned about 50cm inside the lower and the upper edge surfaces were expected to have the smallest burnup error. PA-w system is now being modified in order to measure and analyze the edge effect. If burnup distribution, N of equation (1), predicted by 2D calculation based on count rates of the edge counter is different from the result given by the central counter, the system proceeds to perform the partial 3D analysis which calculates for about 1m length of the axial direction around edge counters. The burnup distribution shape factor N in equation (1) is then decided. The detailed results of the edge effect study will be described in a forthcoming paper.

CONCLUSION

This paper described the principles, system structure, equipment, performance and related studies of the PA-w system being developed by the authors. This system is an effective method for monitoring the burnup and the subcriticality of spent fuels loaded into a cask. The features of the PA-w system are as follows.

- It is based upon the passive neutron measurement method.
- It requires no additional equipment other than the system related to the neutron measurement and the supporting computer system.
- It facilitates the monitoring of both burnup and subcriticality at every step of spent fuel loading process in close to real time.
- The monitoring of neutron behavior enables prediction of a hypothetical criticality accident.
- It enables measurement of the effect of the axial burnup distribution.

Issues of this system are the study of the axial burnup effect including the void fraction of BWR spent fuels, the execution of the measurement tests and the construction of the procedure taking burnup credit with the reactivity measurement system.

REFERENCES

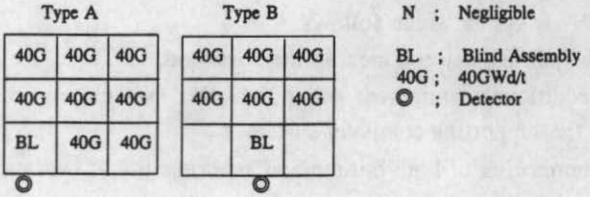
Boyd et al. Effect of Axial Burnup on Fuel Storage Rack Reactivity. Nuclear Plant Journal, vol.9, No.4(1991)

DOE, Topical Report on Actinide-Only Burnup Credit for PWR Spent Nuclear Fuel Packages. DOE/RW-0472 Rev.0(1995)

Ewing et al. Burnup Verification Measurements on Spent-Fuel Assemblies at Oconee Nuclear Station. EPRI TR-103591(1994)

Table 1. Results of Simulation Analysis for Burnup Correction and Reactivity

Burnup of Blind Ass. (GWd/t)	Burnup of Other Ass. (GWd/t)	Iteration Number of 2D(X-Y) Calculation (GWd/t) 0	1	2	3	4	5	6	7	Error of Burnup	Error of Reactivity (dk/k)	Calculation Type
35	40	40	35.6	35.1	**35.0**					N	N	A
45	40	40	44.0	44.9	**45.0**					N	N	A
20	40	40	25.6	23.1	22.0	21.3	20.9	20.6	**20.4**	2 %	< 1 %	B
60	40	40	56.8	59.3	**59.6**					0.7 %	N	B



Type A

40G	40G	40G
40G	40G	40G
BL	40G	40G
○		

Type B

40G	40G	40G
40G	40G	40G
	BL	
	○	

N ; Negligible

BL ; Blind Assembly
40G ; 40GWd/t
○ ; Detector

Table 2. Measurement and Calculation Errors

〈 Measurement Errors 〉			
a. Error of relative position	;	3.5 ~ 5 cm	(1)
b. Error of cooling time	;	1.4 ~ 7.9 years	(1)
c. Error related to burnup history (Specific power, Operation time)	;	< 1 %dk/k	
d. Statistical error of count rates	;	< 1 %dk/k	(2)
〈 Calculation Errors 〉			
a. Error resulted from burned fuel composition	;	1 ~ 2 % dk/k	(3)
b. Error of intrinsic neutron source intensity	;	~ 1 % dk/k	(4)
c. Error of reactivity for burned fuel	;	~ 1 % dk/k	(3)
d. Error for Axial burnup distribution	;	1 ~ 6 % dk/k	(5)

(1)Equivalent to the change of 1 GWd/t
(2)By more than 1,000 neutron counts
(3)DOE/RW-0472 Rev.0(1995)
(4)Ewing et al.(1994)
(5)Boyd et al.(1991)

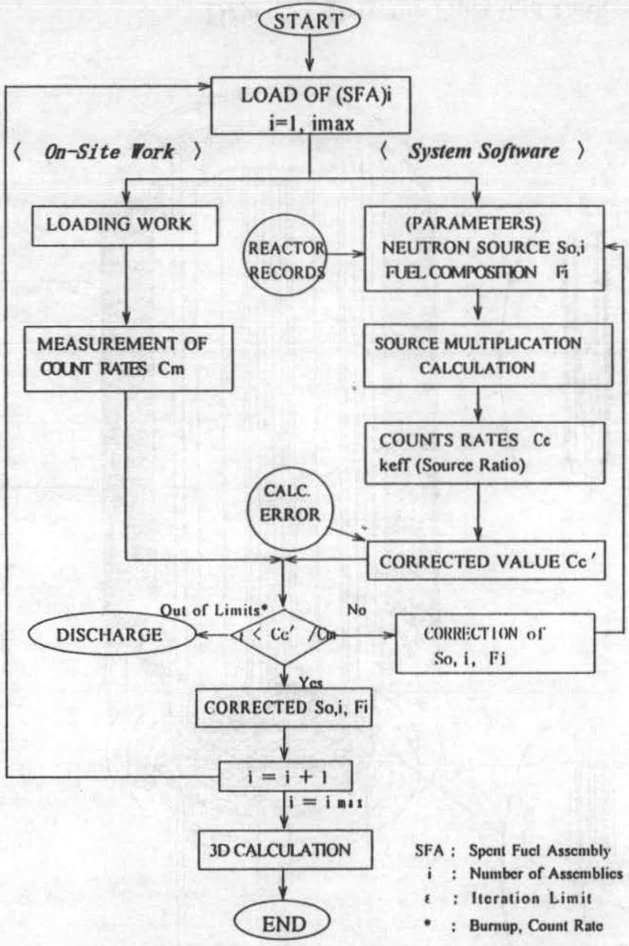


Figure 1. Main Process Flow of PA-w System

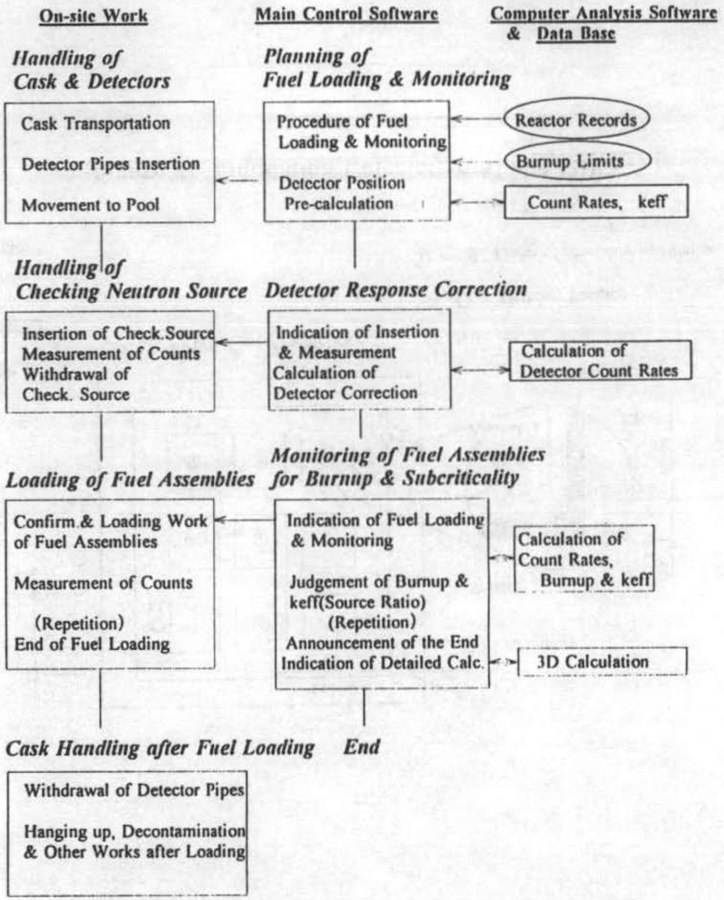


Figure 2. SYSTEM OVERALL STRUCTURE

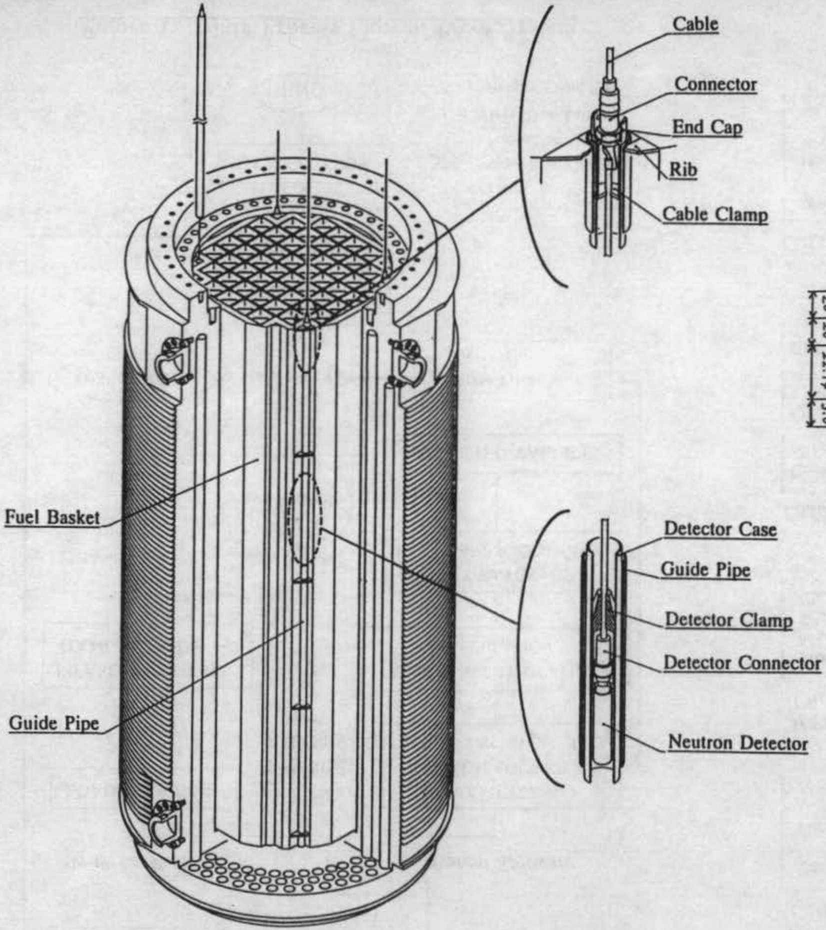


Figure 3. Detector Pipes and Cask

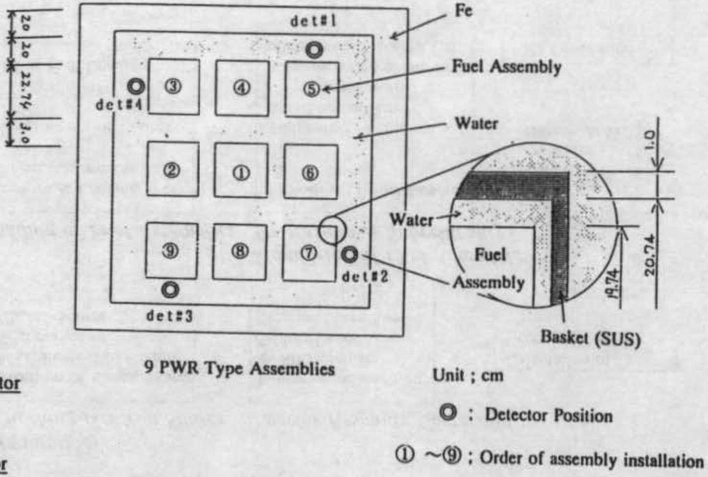


Figure 4. Simulation Calculation Model (2D X-Y)

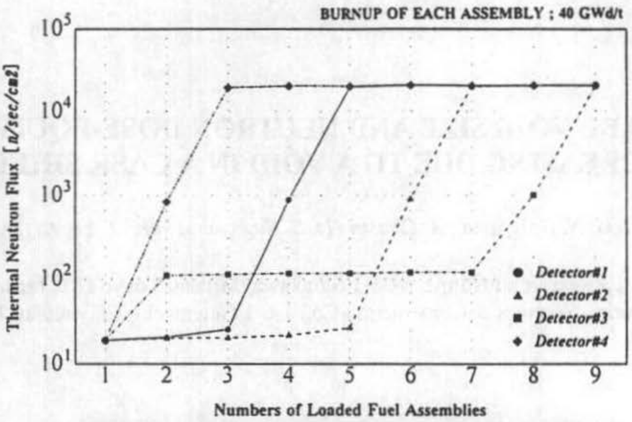


Figure 5. Detector Respose in a Normal Condition

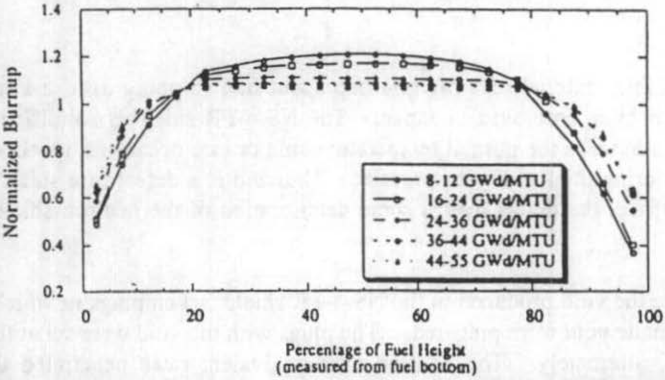


Figure 6. Normalized Axial Burnup Profiles for PWR Fuels (DOE/RW-0472 Rev.0)

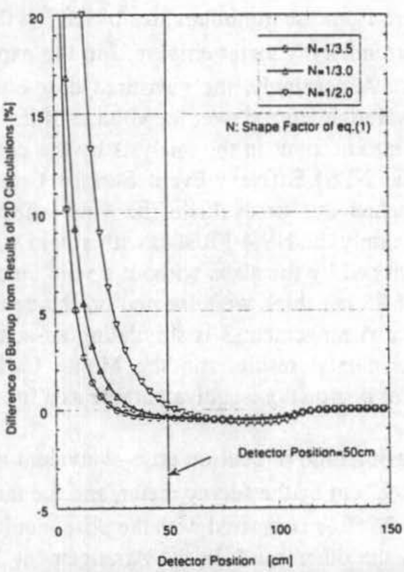


Figure 7. Detector Position and the Burnup Difference