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Use of Rank Sum Method in Identifying High Occupational Dose Jobs for ALARA Implementation

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Abstract

The cost-effective reduction of occupational radiation exposure (ORE) dose at a nuclear power plant could not be achieved without going through an extensive analysis of accumulated ORE dose data of existing plants. It is necessary to identify what are high ORE jobs for ALARA implementation. In this study, the Rank Sum Method (RSM) is used in identifying high ORE jobs. As a case study, the database of ORE-related maintenance and repair jobs for Kori Units 3 and 4 is used for assessment, and top twenty high ORE jobs are identified. The results are also verified and validated using the Friedman test, and RSM is found to be a very efficient way of analyzing the data.

1. Introduction

Pursuant to the requirements of keeping occupational radiation exposure (ORE) as low as reasonably achievable (ALARA), the effective reduction of ORE has always been one of the major concerns in the phases of design as well as operation of a nuclear power plant. Meanwhile, it has been identified that a predominant portion of ORE arises during maintenance and repair operation in a nuclear power plant. Hence, the cost-effective reduction of ORE could not be achieved without going through a comprehensive analysis of accumulated ORE data of existing plants. Towards the goal of this achievement, it is the first step to identify what are the jobs of repetitive high ORE during maintenance and repair operation so that concentrated efforts should be placed on the identified jobs to effectively reduce the ORE dose for ALARA implementation[1].

Each existing nuclear power plant in operation has been accumulating its own ORE data. The data are composed of a set of collective doses according to each maintenance and repair job. Maintenance and repair jobs are first classified to main job codes, and each main job code is further broken down as in detail as possible to detailed job codes. These job codes formulate the structure of radiation job classifications, and each maintenance and repair job in the database will be assigned to one of the radiation job classifications defined in the structure. In consequence, for each radiation job classification, a set of collective ORE dose data will be available.

In general, the data are processed to a mean or median value for assessment, and this point value has been used as a judgement indicator of high radiation job classification[2]. This paper suggests the use of Rank Sum Method (RSM) in identifying high radiation job classifications.[3] The advantage of Rank Sum Method over Point Dose Value Method is that "repetitive" high dose jobs can be identified more effectively. In order to achieve ORE dose reduction more efficiently, "repetitive" high dose jobs are more important than "non-repetitive" high dose jobs. In case the point dose value of some radiation jobs are same, RSM can give ranks to them. In the RSM; 1) the distribution percentiles of collective dose within each given radiation job classification are computed; 2) for each given percentile value, the collective doses of all radiation job classification having the same distribution percentile are ranked in ascending order of magnitude; 3) the ranks of all percentiles are summed for each radiation job classification; and 4) the rank sums are used to rank each radiation job classification for assessment.

As a case study, the database of Kori Units 3 and 4 is used for assessment. As a result of study, top twenty high radiation job classifications are ranked in order and identified. The results are also verified and validated using the Friedman test[4].

2. Rank Sum Method

The Rank Sum Method which is applied to rank the radiation job classifications for effectiveness of ORE reduction consists of four steps.

The first step is to derive the percentile values of collective dose for each radiation job classification. The collective ORE dose data assigned to a given radiation job classification are sorted in order of increasing magnitude, which actually create a distribution function. For convenience of this study, 9 different distribution percentile values are chosen as follows : ξ = 10, 20, ···, 90 percentiles with 10 percentile increment. Table 1 shows how to derive the 9 percentile values from the total collective ORE dose data of a radiation job classification. Example job is SG manway close job whose job code is B2.

Table 1. Spreadsheet for Deriving Percentile Values
Job Code & Title : B2 - SG Manway Close Job

Collective ORE Dose (man-mrem)	Index	CDF	Percentile
D	i	$F(D_i) = i/(N+1)$	
1	1	0.035	
1	2	0.069	
1	3	0.103	≒10th
51	4	0.138	
60	5	0.172	
93	6	0.207	≒20th
123	7	0.241	
128	8	0.276	
157	9	0.310	≒30th
247	10	0.345	
273	11	0.379	
365	12	0.414	≒40th
445	13	0.448	
524	14	0.482	
596	15	0.516	≒50th
717	16	0.552	
890	17	0.586	≒60th
909	18	0.621	
910	19	0.655	
975	20	0.690	≒70th
995	21	0.724	
1005	22	0.759	
1263	23	0.793	≒80th
1390	24	0.828	
1395	25	0.862	
1420	26	0.897	≒90th
1564	27	0.931	
3635	28	0.966	
	N=28		

In this case, for each of N radiation job classifications, 9 values of collective ORE dose corresponding to 9 distribution percentiles are computed, and they are annually normalized values. Annually normalized percentiles of a radiation job classification are calculated by multiplying annual frequency factor to the each percentile derived using total collective ORE dose data distribution.

Let $\{S^j\}$ be a set of collective ORE dose data for radiation job classification j in which the data, S^j_ξ are arranged in ascending order of collective dose as follows :

$$\{S^j\} = \{S^j_\xi ; S^j_{10} \le S^j_{20} \le \cdots \le S^j_{90}\} ; \quad j = 1, 2, \cdots, N \tag{1}$$

where $S^j_{10}, S^j_{20}, S^j_{90}$ are the collective ORE doses (annually normalized) of 10, 20, ··· , 90 percentiles, respectively, which have been classified to radiation job classification j.

The second step is to rank the radiation job classifications according to magnitude of collective dose value of each percentile value. The collective ORE dose data assigned to a given percentile value are sorted in order of increasing magnitude. Using matrix notation, collective ORE doses of all N radiation job classifications are arranged in all nine distribution percentiles as follows:

$$S = \begin{bmatrix} S^1_{10} & S^1_{20} & \cdots & S^1_{90} \\ S^2_{10} & S^2_{20} & \cdots & S^2_{90} \\ \vdots & \vdots & \ddots & \vdots \\ S^N_{10} & S^N_{20} & \cdots & S^N_{90} \end{bmatrix} \tag{2}$$

For a given distribution percentile ξ, let' s arrange the elements of column ξ of Equation 2 in ascending order of collective dose. Staring from 1, the rank assigned to the matrix element (radiation job classification) with the smallest collective dose value for distribution percentile ξ, the ranks of rest successively ascend one-by-one in order of increasing magnitude of collective dose.

Let R^j_ξ denote the rank of S^j_ξ. If we replace the elements of the matrix S^j_ξ with R^j_ξ, the rank matrix becomes

$$R = \begin{bmatrix} R^1_{10} & R^1_{20} & \cdots & R^1_{90} \\ R^2_{10} & R^2_{20} & \cdots & R^2_{90} \\ \vdots & \vdots & \ddots & \vdots \\ R^N_{10} & R^N_{20} & \cdots & R^N_{90} \end{bmatrix} \tag{3}$$

where R^j_ξ is within the range of [1, N].

The third step is to compute the sum of the ranks in each radiation job classification, and to rank the sums. Let $\Sigma R^j_\xi = \sum_\xi R^j_\xi$, which denotes the sum of ranks for radiation job classification j over all 9 percentiles. Then, the rank sum matrix becomes

$$RS = \begin{bmatrix} R^1_{10} & R^1_{20} & \cdots & R^1_{90} & \sum R^1_\xi \\ R^2_{10} & R^2_{20} & \cdots & R^2_{90} & \sum R^2_\xi \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ R^N_{10} & R^N_{20} & \cdots & R^N_{90} & \sum R^N_\xi \end{bmatrix} \tag{4}$$

Let the elements of the far right-hand side column in Equation 4 be sorted in order of increasing magnitude, and let R_j be the rank of the rank sum of radiation job classification j. If we replace ΣR^j_ξ with R_j, the column vector which expresses the rank of each job classification becomes

$$R = col\{\, R^1 \;\; R^2 \;\; \cdots \;\; R^N \,\} \tag{5}$$

The fourth step is to verify and validate the results using the Friedman test. If we replace ΣR^j_ξ with R_j in Equation 4, the Friedman test matrix becomes

$$FT = \begin{bmatrix} R^1_{10} & R^1_{20} & \cdots & R^1_{90} & R^1 \\ R^2_{10} & R^2_{20} & \cdots & R^2_{90} & R^2 \\ \vdots & \vdots & \ddots & \vdots & \vdots \\ R^N_{10} & R^N_{20} & \cdots & R^N_{90} & R^N \end{bmatrix} \tag{6}$$

Equation 6 is used as the source file for the Friedman test[5].

Table 2. Radiation Job Classifications of A Typical PWR Plant

Main Job Code and Title	Detailed Job Code and Title
A Reactor Job	A1 Preparatory Job, A2 Reactor Disassembling, A3 Fuel Withdrawal, A4 Fuel Inspection, A5 Fuel Loading, A6 Reactor Assembling, A7 Reactor Inspection, A8 Others
B SG Manway Job	B1 Manway Open, B2 Manway Close, B3 Others
C SG ECT Job	C1 Preparatory Job, C2 Inspection, C3 Template Construction & Removal, C4 Equipment Installation & Movement, C5 ECT, C6 Others
D SG Tube Job	D1 Preparatory Job, D2 Inspection, D3 Template Construction & Removal, D4 Equipment Installation & Movement, D5 Plugging, D6 Sleeving, D7 Equipment Decontamination, D8 Others
E SG Nozzle Dam Job	E1 Dam Construction, E2 Dam Removal, E3 Others
F SG Lancing Job	F1 Preparatory Job, F2 H/H Job, F3 Lancing, F4 Equipment Removal & Decontamination, F5 Others
G SG Related Other Jobs	
H RCP Check & Maintenance Job	H1 Preparatory Job, H2 RCP Motor Job, H3 RCP Seal and MFB Job, H4 RCP TVCS Job, H5 RCP DACS Replacement, H6 Others
I PZR Check & Maintenance Job	
J RHR Check & Maintenance Job	
K In-Service Inspection	K1 RT, K2 PT, K3 MT, K4 ET, K5 UT, K6 VT, K7 Others
L Containment Leak Test	
M In-Core Job	M1 Thimble Job, M2 DFMS System Job, M3 Thermocouple Job, M4 Detector Job
N RTD Check & Maintenance Job	
O Snubber Check & Maintenance Job	
P Valve Check & Maintenance Job	P1 BB System, P2 BH System, P3 BG System, P4 BM System, P5 BC System, P6 HB System, P7 HC System, P8 Others
Q P/P Check & Maintenance Job	
R Heat Exchanger Check & Maintenance Job	
S Filter Job	
T Evaporator Job	
U Decontamination & Laundry Job	
V Waste Related Job	
W Radiation Safety Control	
X System Operation	
Y Waste Drum Deposit Job	
Z Others	

3. Case Study

3.1. Radiation Job Classifications

Table 1 summarizes the structure of radiation job classifications derived for a typical PWR nuclear power plant[6]. This structure has been adopted for the case study. There are 26 main job codes which are further subdivided into detailed job codes. These job codes, all together constitute 74 radiation job classifications as shown in Table 1.

3.2. Database

For meaningful assessment of ORE, it requires a minimum of 5 years or 4 effective full power years of operation for data collection[7]. Kori Units 3 and 4 are selected for the case study. Kori Units 3 and 4 are PWRs with 950 MWe capacity each and have been operating since 1986 and 1987, respectively. The ORE data used for this case study had been accumulated over a 10-year period starting from 1986 through 1995. These data are analyzed by a PC-based ORE database program, INSTORE[8], and may be categorized in terms of plant unit, job date, work number, main job code and title, detailed job code and title, full job description, average dose rate, job time, crew number, and collective dose.

3.3. Results of Study

Among 74 radiation job classifications shown in Table 1, there are some job classifications which neither are performed in Kori Units 3 and 4, nor have sufficient data for meaningful assessment. Twelve job classifications of this sort are identified and excluded. The rest 62 job classifications are evaluated.

For the assessment, a total of 4,335 collective ORE dose data are obtained. Each one of them is assigned to one of 62 radiation job classifications. For each one of 62 radiation job classifications, a set of nine percentile dose values are computed based upon the assigned dose data. In this way, the collective ORE dose matrix (9×62), **S** is formulated for rank sum analysis.

Arranging the elements of a given column of matrix, **S**, in ascending order of magnitude of collective dose, the ranks are assigned starting from 1 for the smallest and successively ascend one-by-one. Hence, for each column of matrix, **S**, the ranks lie within the range of [1, 62]. When the collective doses are same, the average value is used. The rank matrix, **R**, is assembled by replacing each element of **S** with the rank of the element. The next step is to compute the sum of ranks in each radiation job classification, and to rank the rank sums. Table 2 shows the ranks of each percentile value, rank sums, and ranks of rank sum are summarized for 62 radiation job classifications.

Top 20 high radiation job classifications are identified and presented in Table 3. Since these jobs dominate the major portion of collective ORE doses, they should be closely scrutinized to derive the means of cost-effective ORE reduction in compliance with the requirements of ALARA. To demonstrate the advantage of Rank Sum Method over Point Dose Value Method (e. g. 50 percentile), two example cases are specified in Table 5. In identifying "repetitive" high dose jobs, RSM is proved to be more efficient method than 50 percentile analysis.

Verification and validation of RSM is performed with Friedman test matrix, **FT**, whose elements are composed of ranks of percentile values and rank sums. The Friedman test is performed using SPSSPC[9]. The results of test show that test statistic S, is computed to be 7.1516. This value is compared with the value of $\chi^2_{(9,0.05)}$ which is defined as the upper 0.05 percentile point of the

Table 3. Ranks, Rank Sum, and Rank of Rank Sum of Each Radiation Job Classification in Kori Units 3 and 4

Job	Rank of Each Percentile									Rank	Rank of
Code	10%	20%	30%	40%	50%	60%	70%	80%	90%	Sum	Rank Sum
A1	5.5	25	24	24	31	30	33	32	31	235.5	28
A2	60	57	56	57	58	58	58	58	58	520	58
A3	42	30	26	22	22	15	19	22	21	219	26
A4	21	11.5	8	5	5	7	5	5	5	72.5	6
A5	23	20	13	9	9	5	8	9	12	108	9
A6	50	60	58	61	60	60	61	61	61	532	60
A7	39	35	32	34	29	31	32	30	30	292	34
A8	31	27	28	25	25	23	23	19	16	217	25
B1	44	42	37.5	38	40	40	45	45	44	375.5	42
B2	14	41	42	49	50	54	49	50	46	395	44
B3	5.5	23	33	36	36	36	39	36	39	283.5	33
C1	12	22	19	20	21	21	16	18	15	164	20
C3	43	45	39	41	45	39	38	37	36	363	41
C4	61	52	47	44	39	44	40	41	37	405	46
C5	53	51	52	53	51	52	52	52	51	467	53
C6	33	34	35	33	33	28	26	28	28	278	31
D2	27	16.5	10	7	6	4	4	4	4	82.5	7
D3	48	38	36	32	30	27	34	34	35	314	35
D5	59	46	50	43	57	50	48	44	52	449	51
D7	19	10	7	4	4	2	2	2	2	52	3.5
E1	58	62	62	62	62	62	62	62	62	554	62
E2	32	32	48	50	46	51	50	48	45	402	45
E3	41	28	23	19	14	33	28	23	17	226	27
F1	18	26	22	21	17	20	29	29	27	209	24
F2	56	49	44	45	41	43	46	46	48	418	47
F3	57	54	51	52	48	46	43	42	41	434	48
F4	30	19	17	12	11.5	11	12	11	11	134.5	15
G0	5.5	3.5	6	6	7	6	6	7	10	57	5
H1	54	53	53	54	56	55	53	55	54	487	56
H2	62	61	61	59	59	59	59	59	60	539	61
H3	47	56	57	56	53	53	55	54	53	484	54.5
H4	46	58	59	60	61	61	60	60	59	524	59
H5	17	59	60	58	52	48	54	51	50	449	51
I0	35	33	31	30	34	34	31	27	24	279	32
J0	5.5	3.5	18	16	15	14	21	20	23	136	16
K1	5.5	3.5	5	13	20	24	15	21	26	133	14
K2	45	55	55	55	54	57	56	56	55	488	57
K3	13	8	4	3	3	1	1	1	1	35	2
K4	5.5	3.5	1.5	1	1	3	3	3	3	24.5	1
K5	16	11.5	15	28	28	32	27	25	25	207.5	23
K6	20	16.5	16	15	23	16	17	15	14	152.5	17
K7	34	39	41	40	42	41	42	40	38	357	40
L0	22	13	21	17	13	12	11	12	8	129	13
M1	55	50	49	48	49	49	51	49	49	449	51
M2	49	44	40	39	37	37	35	35	34	350	39
M3	28	21	14	10	10	9	10	8	9	119	10
M4	40	31	27	29	27	26	25	26	22	253	29
NO	24	14	30	27	26	25	20	16	18	200	22
O0	5.5	43	45	46	43	42	41	39	40	344.5	38
P1	52	48	46	47	47	47	47	53	57	444	49
P2	51	47	54	51	55	56	57	57	56	484	54.5
P3	36	36	37.5	37	38	38	37	38	42	339.5	37
P4	5.5	9	25	26	24	18.5	18	17	20	163	18.5
P5	15	18	11	14	11.5	13	13	13	13	121.5	11
P7	11	7	3	2	2	8	7	6	6	52	3.5
P8	38	40	43	42	44	45	44	43	47	386	43
Q0	5.5	3.5	1.5	8	16	18.5	22	24	29	128	12
S0	26	29	29	31	32	29	30	31	33	270	30
U0	29	24	20	23	19	22	14	14	19	175	21
V0	25	15	9	11	8	10	9	10	7	104	8
W0	37	37	34	35	35	35	36	47	43	339	36
Z0	5.5	3.5	12	18	18	17	24	33	32	163	18.5

Table 4. Top Twenty High ORE Dose Jobs in Kori Units 3 and 4

Job Code	Main Job Title	Detailed Job Title	Rank Sum
E1	SG Nozzle Dam Job	Dam Construction	554
H2	RCP Check & Maintenance Job	RCP Motor Job	539
A6	Reactor Job	Reactor Assembling	532
H4	RCP Check & Maintenance Job	RCP TVCS Job	524
A2	Reactor Job	Reactor Disassembling	520
K2	In-Service Inspection	PT	488
H1	RCP Check & Maintenance Job	Preparatory Job	487
P2	Valve Check & Maintenance Job	BH System	484
H3	RCP Check & Maintenance Job	RCP Seal and MFB Job	484
C5	SG ECT Job	ECT	467
M1	In-Core Job	Thimble Job	449
H5	RCP Check & Maintenance Job	RCP DACS Replacement	449
D5	SG Tube Job	Plugging	449
P1	Valve Check & Maintenance Job	BB System	444
F3	SG Lancing Job	Lancing	434
F2	SG Lancing Job	H/H Job	418
C4	SG ECT Job	Equipment Installation & Movement	405
E2	SG Nozzle Dam Job	Dam Removal	402
B2	SG Manway Job	Manway Close	395
P8	Valve Check & Maintenance Job	Others	386

Table 5. Comparison of RSM Result and 50 Percentile Analysis Result

	Job	10%	20%	30%	40%	50%	60%	70%	80%	90%	RSM Rank
Case I	A6	225.6	1212.6	1833	3073.8	3891.6	6034.8	9221.4	14607.6	24111	60
	H4	169.4	954.8	1840.3	2625.7	4019.4	6167.7	8462.3	10741.5	13806.1	59
Case II	P1	260	520	780	1170	1560	2340	3120	5330	10868	49
	F3	396	699.6	937.2	1452	1689.6	2065.5	2349.6	3141.6	3920.4	48

X^2 distribution with degree of freedom of 9. The comparison of two values shows that S is less than the value of $X^2_{(9,0.05)}$ (= 16.92), which means that 10 samples (9 percentile values plus 1 rank sum value) have the characteristics of good homogeneity and well describe the characteristics of a population.

4. Conclusions

The effective reduction of ORE in a nuclear power plant could be achieved by analyzing existing ORE data, drawing high occupational radiation jobs from the data using statistical analysis, and finally adopting appropriate means to reduce ORE based upon the results of analysis. The Rank Sum Method is used in identifying high occupational radiation jobs. As a case study, it is actually applied to ORE database of Kori Units 3 and 4, and RSM is found to be a very efficient way of analyzing the data.

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