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Prediction of the Volume of Solid Radioactive Wastes to be Generated from Korean Next Generation Reactor

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Abstract

Correlations between the amount of DAW (Dry Active Waste) generated from present Korean PWRs and their operating parameters were analyzed. As the result of multi-variable linear regressions, a model predicting the volume of DAW using the number of shutdowns (f_{FS}) and total personnel exposure (P_E) was derived. Considering one standard error bound, the model could successfully simulate about 85% of the real data. In order to predict the amount of DAW to be generated from a KNGR, another model was derived by taking into account the additional volume reduction by supercompaction system. In addition, the volume of WAW (Wet Active Waste) to be generated from KNGR (Korean Next Generation Reactor) was calculated by considering conceptual design data and replacement effect of radwaste evaporator with selective ion exchangers. Finally, total volume of SRW (Solid Radioactive Waste) to be generated from KNGR was predicted by inserting design goal values of f_{FS} and P_E into the model. The result showed that the expected amount of SRW to be generated from KNGR would be in the range of 33 ~ 44 $m^3 \cdot y^{-1}$. It was proved that the value would meet the operational target of KNGR proposed by KEPCO, that is, 50 $m^3 \cdot y^{-1}$.

1. Introduction

The radioactive wastes generated and released from NPPs (Nuclear Power Plants) are usually categorized into three types according to their physico-chemical forms; that is, LRW (Liquid Radioactive Waste), GRW (Gaseous Radioactive Waste), and SRW (Solid Radioactive Waste). The annual amounts of LRW and GRW released from NPPs are usually described as activity (i.e. $Ci \cdot y^{-1}$), and that of SRW is expressed as volume (i.e. $m^3 \cdot y^{-1}$ or $ft^3 \cdot y^{-1}$).

The amounts of radioactive wastes generated from NPPs are very important in the aspects of environmental, radiological safety, and economics of radioactive waste disposal. Until now, many methods to reduce the amounts of radioactive wastes have been developed and used in NPPs. Also the amount of each radioactive waste stream is expected to be further diminished in the future.

In general, a computerized mathematical model for calculating the releases in gaseous and liquid effluents, named PWR-GALE (Pressurized Water Reactor-Gaseous And Liquid Effluents) code has been widely used [1]. U.S.NRC (Nuclear Regulatory Commission) uses the code to determine conformance with the requirements of 10CFR50 Appendix I.

However, there is no good mathematical model for SRW, such as PWR-GALE code for LRW and GRW, which plant engineers and operators can use for prediction of annual volume generation. This is because the amount of SRW —especially DAW (Dry Active Waste)—, depends upon the plant's operation history rather than the pre-determined design parameters. EPRI (Electric Power Research Institute) has recommended to use the results of Sargent and Lundy's study, for deriving the amounts of DAW and WAW (Wet Active Waste), as a foundation [2,3,4].

The main purpose of this study is developing a regression model for assesing the amount of DAW generated from Korean PWRs, by use of real plant operation data. In addition, it is also shown that the method can be applied to predict the amount of DAW which is to be generated from a KNGR.

Recently, public concerns about the environmental problems which would be caused by radioactive materials are rapidly increasing. Therefore, many utilities have continued to reduce the amount of radioactive wastes generated from NPPs, by adopting new waste treatment systems or improving their operating techniques. Due to the continuously increasing waste disposal cost and land requirement problems, the VR (volume reduction) becomes relatively important in the case of SRW. Therefore a series of requirements or target values is specified to the quantities of waste which is to be generated from some advanced nuclear reactors, as shown in Table 1.

In this study, the amount of WAW generated from a KNGR is also to be calculated by considering a few design requirements sepcified to RWPS (Radioactive Waste Processing System) of the KNGR. Finally, the predicted value for the whole volume of SRW (i.e. sum of the quantities of DAW and WAW) will be compared to the operational target value of the KNGR and validity of the target value will be verified.

2. Methodology and Requirements

There exist a few methods to calculate the amount of SRW generated from an NPP, and they are generally divided into two models; that is, comparative model and predictive one [3].

2.1. Comparative Model

One of the most commonly used comparative models is the waste volume comparison method which allows plant operators to visualize a plant's overall waste management performance in relation to the rest of the industry based upon volume of waste generated or shipped. On the other hand, a waste index comparison method eliminates the systematic effects common to all reactors in order to emphasize potential differences in waste generation due to the waste management programs and practices.

DWI (Dry Waste Index) is a normalized reference index used to compare the DAW volume of different units on the basis of outage conditions [3]. The DWI allows plant's operators to determine their relative performance at minimizing DAW generation based upon the outage conditions. The DWI can be written as:

$$DWI = \frac{V_{DAW}}{(1-A_f)\cdot O_f}\ , \tag{1}$$

Table 1. Annual Average Amount of SRW to be Generated from Some APWRs

	KNGR (Target)	EPRI-URD (Requirements)	System80+ (Expected Value)	AP-600 (Expected Value)
GRW	$200\ Ci\cdot y^{-1}$	$200\ Ci\cdot y^{-1}$	$1545\ Ci\cdot y^{-1}$	$4100\ Ci\cdot y^{-1}$
LRW	$0.05\ Ci\cdot y^{-1}$	$0.05\ Ci\cdot y^{-1}$	$0.939\ Ci\cdot y^{-1}$	$0.26\ Ci\cdot y^{-1}$
SRW	$50\ m^3\cdot y^{-1}$	$1{,}750\ ft^3\cdot y^{-1}$	$4{,}005\ ft^3\cdot y^{-1}$	$1{,}729\ ft^3\cdot y^{-1}$

where V_{DAW} is the annual average volume of the DAW [ft^3], A_f is the unit availability factor, and O_f is the outage intensity factor.

Similar to the DWI, WWI (Wet Waste Index) allows for plant comparison on an equal basis by considering those systematic operational factors most frequently identified by plant operators as influencing the generation of WAW. The WWI, as shown in Eq. 2, allows plant operators to determine their relative performance at minimizing WAW generation based upon the operating conditions.

$$WWI = \frac{V_{WAW}}{A_f \cdot f_{FS}^{1/3}} , \qquad (2)$$

where V_{WAW} is the annual average volume of WAW [ft^3], and f_{FS} is the annual average number of forced shutdowns.

2.2. Predictive Model

The two previous comparison methods allow for the relative comparison of plants based upon the factors reported by plant personnel as having the greatest influence on SRW generation. These methods cannot predict how much waste a plant would produce based upon its operational conditions. Therefore, an attempt was made to develop a predictive model for the generation of DAW from PWR based upon correlations between plant operational parameters and waste generation. EPRI has derived a predictive model to calculate the annual amount [$ft^3 \cdot y^{-1}$] of DAW generated from an American PWR as follows [3]:

$$V_{DAW}\,[ft^3/y] = 6.3 \cdot P_E + 160 \cdot f_{FS} + 5.2 \cdot N_p + 8.3 \cdot E_x - 5{,}000 , \qquad (3)$$

where P_E is the electric power of plant [MWe], N_p is the number of personnel onsite with measurable exposure, and E_x is the total personnel exposure [$person \cdot rem$].

It is generally known that the generation of DAW is related to the operation and maintenance history of an NPP. However, the volume of WAW depends on the design parameters of each plant's RWPS. Eq. 3 is a model derived from statistical calculations of plant operating paremeters and the volume of DAW from PWRs in the United States from 1978 to 1981. However, Eq.3 is derived from the American PWRs which have quite different operating conditions compared to Korean PWRs. Both fresh and salt waters are utilized as cooling water sources in the American PWRs, and some plants use evaporators and others have demineralizers for processing LRW. Therefore it is inappropriate to apply Eq.3 directly to the Korean PWRs, and it is necessary to derive a new predictive model. In this study, we derived a DAW predictive model by a series of statistical manipulations of the data obtained from the Korean PWRs.

3. Modeling

3.1. DAW Generated from Korean PWRs

3.1.1. Data Preparation

The volumes of SRW annually generated from eight PWRs operating in Korea are shown in Table 2 [5-11]. Data for seven years (1988 to 1994) were collected and analyzed, however, the data for Ulchin 1 & 2 were limited to only five years (1990~1994), since the units started their commercial operation in Sep. 1988 and Sep. 1989, respectively.

The SRW generated from the present Korean PWRs are classified into CW (Concentrate Waste), SR (Spent Resin), SF (Spent Filter), and MW (Miscellaneous Waste). In this study, CW and SR are categorized as WAW, and the rest are categorized as DAW. Six plants of the eight Korean PWRs (Kori 3 & 4, Yonggwang 1 & 2, and Ulchin 1 & 2) are twin, and they share SRWPS (Solid Radioactive Waste Processing System) each other. Therefore, it can be assumed that the same amounts of SRW are generated from each unit of the twin plants.

Table 2. Annual Ammount of SRW Generated from Korean PWRs and Adjusted Data for KNGR

[Unit : 200-ℓ Drums]

Unit	Year	CW	SR	Total WAW	SF	MW	Total DAW	Adjusted MW	Adjusted Total DAW
Kori 1 & 2	1988	344	146	490	23	1,143	1,166	571.5	594.5
	1989	326	154	480	30	778	808	389.0	419.0
	1990	356	142	498	25	1,014	1,039	507.0	532.0
	1991	287	74	361	21	709	730	354.5	375.5
	1992	172	79	251	19	851	870	425.5	444.5
	1993	197	92	289	10	748	758	374.0	384.0
	1994	134	47	181	5	311	316	155.5	160.5
Kori 3 & 4	1988	235	245	480	39	518	557	259.0	298.0
	1989	459	212	671	26	695	721	347.5	373.5
	1990	238	131	369	15	570	585	285.0	300.0
	1991	288	156	444	25	569	594	284.5	309.5
	1992	332	52	384	28	666	694	333.0	361.0
	1993	226	66	292	47	609	656	304.5	351.5
	1994	185	54	239	12	488	500	244.0	256.0
Yong-gwang 1 & 2	1988	132	134	266	0	347	347	173.5	173.5
	1989	270	33	303	0	618	618	309.0	309.5
	1990	586	0	586	12	698	710	349.0	361.0
	1991	520	0	520	0	470	470	235.0	235.0
	1992	583	110	693	10	373	383	186.5	196.5
	1993	307	60	367	9	512	521	256.0	265.0
	1994	336	165	501	5	330	335	165.0	170.0
Ulchin 1 & 2	1988	3	0	3	6	33	39	16.5	22.5
	1989	342	0	342	29	345	374	172.5	201.5
	1990	264	102	366	52	506	558	253.0	305.0
	1991	372	231	603	26	452	478	226.0	252.0
	1992	447	210	657	29	391	420	195.5	224.5
	1993	462	153	615	39	334	373	167.0	206.0
	1994	366	212	578	35	405	440	202.5	237.5

※ CW : Concentrate Waste, SR : Spent Resin, SF : Spent Filter, and MW : Miscellaneous Waste.

3.1.2. Parameter Analysis

In this study, we chose five operating and design parameters that would be expected to affect the amount of DAW, and analyzed their correlations. This analysis was performed only for the cases which had linear correlations, since nonlinear correlations were almost impossible to interpret or to give any physical meanings. The five parameters selected in this study are electric power of plant (P_E), annual number of forced shutdowns (f_{FS}), annual number of total shutdowns (f_{TS}), number of personnels onsite (N_P), and total personnel exposure (E_x).

As the result of preliminary analysis of the five parameters, four of them (f_{FS}, f_{TS}, N_P, and E_x) have relatively strong linear correlations with the amount of DAW [3]. It is generally reported that the electric power of PWR is proportional to the amount of DAW. However, the effect of P_E on V_{DAW} was not observed in this study.

Table 3. Operating Parameters of Korean PWRs

Unit	Power [MWe]	Year	f_{FS}	f_{TS}	N_P [Person]	E_X [Person·Rem]
Kori 1 & 2	587	1988	1 + 0	2 + 1	1,549	974.80
		1989	3 + 3	4 + 4	1,260	616.60
		1990	2 + 0	3 + 1	1,602	603.50
		1991	11 + 1	11 + 2	1,251	180.18
	650	1992	4 + 1	6 + 2	1,304	429.40
		1993	1 + 2	2 + 3	1,293	454.60
		1994	1 + 1	3 + 2	1.365	316.40
Kori 3 & 4	950	1988	1 + 3	2 + 4	1,405	520.80
		1989	0 + 1	2 + 3	1,277	368.80
		1990	3 + 3	4 + 5	1,793	232.00
		1991	0 + 2	4 + 3	1,721	276.30
		1992	0 + 4	1 + 5	1,628	213.70
		1993	3 + 3	4 + 4	1,485	223.10
		1994	0 + 1	1 + 3	1,414	190.50
Yonggwang 1 & 2	950	1988	2 + 2	4 + 3	1,472	408.90
		1989	1 + 2	2 + 5	1,460	315.56
		1990	2 + 1	3 + 4	1,553	373.59
		1991	1 + 2	2 + 3	1,265	191.03
		1992	1 + 3	2 + 4	1,360	173.60
		1993	0 + 2	1 + 4	1,398	180.90
		1994	1 + 0	1 + 1	1,158	124.40
Ulchin 1 & 2	950	1988	–	–	–	–
		1989	–	–	–	–
		1990	3 + 3	4 + 5	1,178	162.86
		1991	3 + 1	6 + 2	1,176	115.14
		1992	1 + 0	2 + 1	1,193	179.30
		1993	1 + 1	2 + 2	1,137	239.30
		1994	0 + 1	1 + 2	1,258	180.80

3.1.3. Statistical Manipulation

Finally four parameters which have relatively strong linear correlations with the DAW were chosen for further statistical manipulations. All the data shown in Table 3 were rearranged by calculating the average values during the assessment period; that is, from 1988 to 1994. In addition, multi-variable linear regressions were made using SAS (Statistical Analysis System) package [12,13].

The largest number of independent variables are three -except the intercept and only four kinds of data are available for the present Korean PWRs. Therefore, six multiple regression models (A-1 to A-6) which have two or three independent variables

Table 4. Proposed Multiple Linear Regression Models

Model		Model Formula
A−1	B−1	$V_{DAW} = \beta_0 + \beta_1 \cdot f_{FS} + \beta_2 \cdot N_p + \beta_3 \cdot E_x$
A−2	B−2	$V_{DAW} = \beta_0 + \beta_1 \cdot f_{FS} + \beta_2$
A−3	B−3	$V_{DAW} = \beta_0 + \beta_1 \cdot f_{FS} + \beta_2$
A−4	B−4	$V_{DAW} = \beta_0 + \beta_1 \cdot f_{TS} + \beta_2 \cdot N_p + \beta_3 \cdot E_x$
A−5	B−5	$V_{DAW} = \beta_0 + \beta_1 \cdot f_{TS} + \beta_2$
A−6	B−6	$V_{DAW} = \beta_0 + \beta_1 \cdot f_{TS} + \beta_2$

Table 5. Results of Regression : Model A-1 to A-6

Model \ Parameter	β_0	β_1	β_2	β_3
A−1 (R2 = 0.6410)	18.095233 ±108.44730870	21.311488 ±11.18864571	0.171971 ±0.15983516	0.803568 ±0.14688415
A−2 (R^2 = 0.6221)	128.937067 ±33.99370183	21.688676 ±11.22140519	0.850341 ±0.14078363	.
A−3 (R^2 = 0.1495)	−13.679466 ±162.77811088	13.913526 ±16.68351202	0.421539 ±0.22962912	.
A−4 (R^2 = 0.6366)	19.237070 ±21.175854	21.175854 ±11.62140269	0.126410 ±0.16354475	0.821858 ±0.14956980
A−5 (R^2 = 0.6267)	95.744812 ±45.5346177	22.836717 ±11.32063472	0.858942 ±0.14042078	.
A−6 (R^2 = 0.1379)	−10.905978 ±164.17642410	8.312305 ±17.14767891	0.414671 ±0.23334608	.

were selected as shown in Table 4, and a series of regressions was performed for each model. The final results are shown in Table 5.

All the regression models (A-1 to A-6) have positive coefficients except the intercept. The models A-3 and A-6 have very small values of R^2; 0.1495 and 0.1379, respectively. These two models were firstly excluded because they could simulate less than 15% of the real data. The values of R^2 for A-1, A-2, A-4, and A-5 are nearly the same, that is, all of them are in the range of 0.62~0.65. In the case of two models A-1 and A-4, however, the uncertainties involved in the coefficient of intercept are too large. Accordingly the two models were not taken into account in the further analysis.

In addition, the standard deviation for the intercept of model A-5, is much larger than that of model A-2. According to the ANOVA (ANalysis Of VAriance) table of the model A-2, the standard error for all parameters are reasonably small, and t-values are meaningful in the level of $p<0.07$. Therefore the model A-2 was finally chosen as an adequate prediction model.

The selected model for predicting the annual amount of DAW generated from a unit of the present Korean PWRs can be rewritten as :

$$V_{DAW}\,[m^3/y] = (25.78\pm6.80) + (4.34\pm2.24)\cdot f_{FS} + (0.17\pm0.03)\cdot E_x\,. \quad (4)$$

Fig.1 shows how the prediction model precisely simulate the real data. The abscisa of the plot represents serial numbers for each data (i.e. total of twenty six data sets). On the other hand, the ordinate of the plot displays the ratio of the predicted values to the

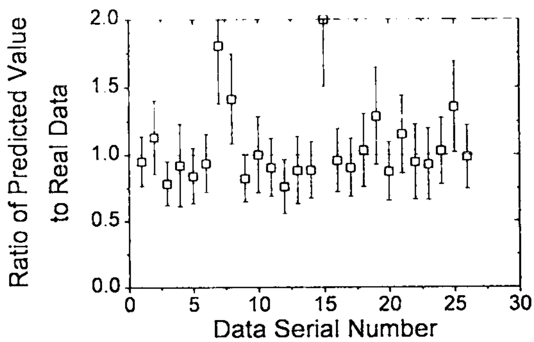

Fig. 1. Ratios of Predicted DAW Volumes to Real Data (Ratio close to unity represents good prediction. Both upper and lower limits for each plot shows one standard deviation from the mean value. Taking into account of a certain error bound of one standard deviation, 22 of total 26 data sets (≈85%) of real data can be successfully simulated.)

real data. Fig. 1 also shows that about 85% (i.e. 22 of 26 data points) of the real plant data can be successfully predicted by Eq.4 in the error bound of one standard deviation.

3.2. DAW to be Generated from KNGR

Eq.4 was derived by a series of statistical manipulations of the data obtained from the present Korean PWRs in operation. Therefore the equation has innate limitations ; that is, it can be applied only to the PWRs with similar design parameters and SRWPS to the existing Korean PWRs.

A series of volume reduction programs such as evaporator concentrates drying systems have been proceeded mainly by KEPCO since 1990. The programs consist of supercompaction system, CWDS (Concentrate Waste Drying System), and DAW sorting/segregation system. As a part of them, a mobile supercompactor was installed at Kori site. DAW VR programs will reduce the waste volume to the one-third of the current practice [14]. It is expected that the supercompactor will be installed in KNGR [15]. According to the KEPRI report, however, the radwaste evaporation system is to be excluded from KNGR.

In this study, we have attempted to develop a prediction model, similar to Eq.4, for KNGR. However it was absolutely impossible to obtain the actual data regarding the DAW volume which is to be generated from KNGR. Therefore, we have tried to adjust the data obtained from the existing PWRs in order to consider the VR effect caused by the supercompactor. At first, we assumed that a supercompactor (2, 000 ton of compaction force) would replace the existing drum compactor (100 ton of compaction force) in KNGR. The amount of miscellaneous waste to be generated from a unit of KNGR could be reduced to half of the volume generated from the present PWRs. For simplification, we also assumed that the amount of SF could be negligible, since the volume of the SF is generally much smaller than that of the MW.

We adjusted the data in Table 2, according to the above assumptions, and regenerated the data compatible with KNGR. We also preliminarily analyzed five operational parameters and design parameters (P_E, f_{FS}, f_{TS}, N_p, and E_x) and examined their linear correlations with the amount of DAW. As a result, four of them −except P_E− were also proved to have relatively strong linear correlations with the amount of DAW.

Table 6. Results of Regression : Model B-1 to B-6

Parameter / Model	β_0	β_1	β_2	β_3
B−1 (R^2 = 0.6286)	17.612605 ±55.97308474	11.256141 ±5.77481380	0.078741 ±0.08249598	0.405741 ±0.07581156
B−2 (R^2 = 0.6133)	68.364546 ±17.45156912	11.428847 ±5.76080620	0.427158 ±0.07227501	.
B−3 (R^2 = 0.1451)	−1.473160 ±82.88854128	7.211814 ±8.49544185	0.209413 ±0.11692987	.
B−4 (R^2 = 0.6235)	18.275300 ±56.36705087	11.147962 ±6.00296393	0.054773 ±0.08447803	0.415307 ±0.07725936
B−5 (R^2 = 0.6163)	51.425615 ±23.42831233	11.867603 ±5.82465033	0.431375 ±0.07224877	.
B−6 (R^2 = 0.1290)	3.043210 ±83.74393025	4.647666 ±8.74677369	0.200439 ±0.11902633	.

Almost the same statistical manipulations were performed as those done in the previous section. That is, a total of six regression models (B-1 to B-6) were proposed as shown in Table 4. The results obtained from the multi-variable linear regressions are also presented in Table 6. The best prediction model for the amount of DAW to be generated from KNGR is :

$$V_{DAW}\,[m^3 \cdot y^{-1}] = (13.67 \pm 3.49) + (2.29 \pm 1.15) \cdot f_{FS} + (0.09 \pm 0.01) \cdot E_x \quad . \qquad (5)$$

3.3. WAW to be Generated from KNGR

The amount of WAW to be generated from KNGR was calculated by use of LRWPS/SRWPS design concepts of KNGR and the assessment method proposed by S. Levy Inc. [15,16]. The treatment methods which are to be implemented into the LRWPS /SRWPS of KNGR are summarized in Table 7. The basic assumptions adopted in this study are as follows : ① radwaste evaporator is to be replaced with demineralizers, therefore CW would not be generated, ②

Table 7. WAW Generation Sources and Systems of KNGR

	Wet Active Waste	
	Filter Cartridge	Spent Resin
Generation Sources and Systems	① Letdown System ② Reactor Coolant System ③ Seal Water Injection ④ Seal Water Return ⑤ Boric Acid ⑥ Miscellaneous Boron Recovery System ⑦ Fuel Pool Purification ⑧ Fuel Pool Skimmer ⑨ Radwaste System	① CVCS Mixed Bed ② CVCS Cation Bed ③ CVCS Deborating System ④ Miscellaneous BRS ⑤ Fuel Pool ⑥ Radwaste System

Table 8. General Features of LRWPS/SRWPS of KNGR

	LRWPS
Major Processes	① Ion Exchange (i.e. Organic Resin and Ion-Selective Inorganic Ion Exchanger) ② Filtration ③ BRS Evaporator
Miscellaneous Features	① Radwaste evaporator would be replaced with ion exchangers in order to reduce operational complexities. ② Oil separator is to be installed. ③ Waste streams are to be treated after sorting and segregation for maxmizing process efficiency.
	SRWPS
Major Processes	① Compaction/Supercompaction ② Dewatering (for WAW such as spent resin and filter sludge) ③ Immobilization/Solidification
Miscellaneous Features	① Radwaste evaporator concentrates are not to be generated. ② Incinerator is to be excluded. ③ Wastse classification table is to be installed.

Cs/Co-selective ion exchange beds are adopted, ③ clean borated wastes are recycled, ④ MW and dirty wastes are discharged, and ⑤ WAW is generated from the systems (or sources) as listed in Table 8.

The annual amount of WAW generated from the LRWPS of KNGR can be written as :

$$W_{rw}=\frac{W_{misc}}{V_m} \quad , \tag{6}$$

where,

W_{rw} = the annual amount of WAW generated from LRWPS [$m^3 \cdot y^{-1}$],

W_{misc} = *the annual throughput of miscellaneous waste in LRWPS [$m^3 \cdot y^{-1}$],*

V_m = the treatment capacity of ion exchange resin for MW [$m^3 \cdot m^{-3}$].

The annual amount of filter cartridges generated from the systems -except the LRWPS- is calculated as follows :

$$W_f = 12 \cdot (R_{all}+R_r) \cdot V_f \ , \tag{7}$$

where,

W_f = The annual amount of filter cartridges generated from the systems-except the LRWPS−[$m^3 \cdot y^{-1}$],

12 = unit conversion factor [month $\cdot\ y^{-1}$],

R_{all} = monthly average numbers of filters replaced in the other systems [$month^{-1}$],

R_r = monthly average numbers of filters replaced in the LRWPS [$month^{-1}$],

V_f = weighted average values of the disposal volume of filter cartridges [m^3].

The annual amount of SR generated from the systems −except the LRWPS− can be calculated as follows :

$$W_{rs}=V_{IX}\cdot\left[(IX_L+IX_{BRS}+IX_{FP})+\frac{1}{FC}(IX_{Cs}+IX_{Co}+IX_B)\right] \ , \tag{8}$$

where,

W_{rs} = annual amount of SR generated [$m^3 \cdot y^{-1}$],

V_{IX} = average volume of ion exchange beds [m^3]

IX_L = annual average numbers of the letdown purification ion exchange beds [y^{-1}],

IX_{BRS} = annual average numbers of the BRS ion exchange beds [y^{-1}],

IX_{FP} = annual average numbers of the fuel pool ion exchange beds [y^{-1}],

IX_{Cs} = numbers of Cs-selective ion exchange beds used in one fuel cycle [y^{-1}],

IX_{Co} = numbers of Co-selective ion exchange beds used in one fuel cycle [y^{-1}],

IX_B = *numbers of B-removal ion exchange beds used in one fuel cycle [y^{-1}],*

FC = period of one fuel cycle [y].

Finally, the annual average amount of the WAW generated from KNGR can be calculated by summing the amount of the WAW generated from the LRWPS (Eqs.6, 7, and 8), and the amount of filter cartridges and SR generated from the systems −except the LRWPS− as follows :

$$\dot{V}_{WAW}=W_{rw}+W_f+W_{rs} \ . \tag{9}$$

4. Results and Discussion

The prediction model to calculate the annual amount of the DAW to be generated from KNGR in which a supercompactor would be adopted, was proposed as Eq.5. In addition, the annual amount of the WAW could be anticipated using Eq.9, for the reactor, in which waste evaporators are to be replaced with selective ion exchangers. We used the design and operating parameters, as shown in Table 9.

The number of forced shutdowns and total personnel exposure are required to assess the amount of DAW to be generated from KNGR. Based on the KEPRI report [16], we assumed that the values of f_{FS} and P_E are 0.8 y^{-1} and 100 person-rem $\cdot\ y^{-1}$, respectively. The calculation result showed that the expected annual volume of the DAW would be 24.50±5.41 $m^3 \cdot y^{-1}$.

In order to assess the amount of the WAW expected to be generated from KNGR, a series of system-

Table 9. Input Parameters Used for Assessment of WAW

Parameter	Assumed Value	Dimension	Parameter	Assumed Value	Dimension
W_{misc}	4.54×10^{3}	$[m^3\cdot y^{-1}]$	IX_{BRS}	1	$[y^{-1}]$
V_m	6.68×102	$[m^3\cdot m^{-3}]$	IX_{FP}	1	$[y^{-1}]$
R_{all}	3	$[month^{-1}]$	IX_{Cs}	1	$[y^{-1}]$
R_r	2	$[month^{-1}]$	IX_{Co}	1	$[y^{-1}]$
V_f	4.25×10^{-2}	$[m^3]$	IX_B	1	$[y^{-1}]$
V_{IX}	9.91×10^{-1}	$[m^3]$	FC	1.5	[y]
IX_L	1	$[y^{-1}]$			

Table 10. Calculated Amount of WAW to Be Generated from KNGR

Waste	Volume $[m^3\cdot y^{-1}]$	Adopted Equation
W_{rw}	6.80	Eq.6
W_f	2.55	Eq.7
W_{ri}	4.96	Eq.8
WAW Total	14.31	Eq.9

atic and design parameters should be known. A set of these parameters has been reported by S. Levy Inc. [17], and most of the values were directly used in this study.

The assumed parameters for the LRWPS of KNGR are listed in Table 9 and they were inserted into Eq.9 for predicting the amount of the WAW. The calculated volume was 14.31 $m^3\cdot y^{-1}$ as summarized in Table 10.

Finally the total volume of the SRW was estimated to be in the range of 33~44 $m^3\cdot y^{-1}$. This value was statistically derived based on the past operational data of the Korean PWRs. Accordingly, the absolute value can be quite widely varied depending on the specifically considered periods (currently, 1988 to 1994). The ultimate result of this study shows that the annual amount of the SRW which is to be generated from KNGR can almost meet the operational target for the SRW generation. That is, the annual amount of the SRW to be generated from future Korean PWRs can be reduced to about 200 drums (200-ℓ drum package) just when a supercompactor and Cs/Co-selective ion exchangers are to be used instead of low pressure balers and waste evaporators, respectively.

5. Conclusions

Using some assumptions, the annual amount of the SRW generated from KNGR was estimated to be 38.81 ± 5.41 $m^3\cdot y^{-1}$; that is, 194 ± 27 drums $\cdot\ y^{-1}$. It can be concluded that the volume is quite close to the operational target volume of the SRW to be annualy generated from a KNGR (i.e. 50 $m^3\cdot y^{-1}$). For comparison, EPRI-URD [2] has proposed the requirement for the annual amount of the SRW generated from an advanced PWR as 1750 $ft^3\cdot y^{-1}$ (or 49.50 $m^3\cdot y^{-1}$).

These values estimated in this study were assessed on the basis of a few assumptions, and the prediction model such as Eq.5 was derived by a series of statistical manipulations and parameter adjustments.

It is anticipated that the prediction model can be used for rough estimation and preliminary anticipation for plant designers. But the model proposed in this study has its own innate limitations, since the number of available data (totally 26 data sets in this study) was quite few to be statistically meaningful. The methodology for deriving the proposed model in this study, however, may be served as a prototype. And the prediction model can be re-derived and updated whenever more data sets can be obtained in the future.

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