Proceedings of the Korean Nuclear Society Autumn Meeting
Seoul, Korea, October 1998

Development of Evaluation Code for Source Term at RCS of Nuclear Power Plant in Korea

Ho Jin Lee and Kun Jai Lee

Korea Advanced Institute of Science and Technology
Department of Nuclear Engineering
373-1 Kusong-dong, Yusong-gu
Taejon, Korea 305-701

Seung Ho Cho and Tae Won Suk

Korea Institute of Nuclear Safety
114 Kusong-dong, Yusong-gu
Taejon, Korea 305-701

Abstract

The amount of radioactive materials released from nuclear power plant must be evaluated before construction stage for the design of bulk shielding and radioactive systems. These methodologies are developed from the mid of 1970s to the mid of 1980s. Since 1985, any new methodologies is not provided. The purpose of this study is to provide a method and evaluation tool for a set of typical radionuclide concentrations at RCS. These concentrations are the predominant factor at evaluation of the expected source term that is the amount of radioactive materials released from nuclear power plant. In this study, an evaluation method for radionuclide concentrations at primary coolant is suggested and a tool for source term is developed. The code named as SYCOS(SYstem for Calculation of Source term) is able to provide the radioactivity at coolant region based on two kinds of methods. One is using ORIGEN 2, another is using a simplified equation for estimation of the radioactivity of fission product at fuel pellet region. For coolant region, a simplified equation assuming the equilibrium state is used. As applying SYCOS to YGN unit 3, 4, the results is compared with the actual measured data from objective plants. The comparison shows that the results from SYCOS are similar to the actual radioactivity distribution except for Xe-133 and Xe-135. Especially, for the change of fuel defect rate from 0.05% to 0.12%, the results from SYCOS are nearly same as the actual data.

1. Introduction

Typically, radioactive source terms are used for shielding design, ensuring adequacy of ventilation, design of radioactive systems, calculation of expected gaseous and liquid releases from the plant and accident analysis. Several methodologies to predict the released amount of radioactive materials are adopted by utility and regulation body. These methodologies are developed from the mid of 1970s to the mid of 1980s. Since 1985, any new methodologies for source term evaluation is not provided. Although, at present, a few codes such as PWR-GALE, DAMSAM are used for evaluation of source term, these codes have some limitation at applying to plant of Korea. PWR-GALE is used for estimation of the expected source term, and radionuclide concentrations used in PWR-GALE are based on the actual data measured from operating plants. Especially, the radionuclide concentrations are the predominant factor in estimation of the radioactivity in the principal fluid streams of a light water reactor over its lifetime. Because radionuclide concentrations at RCS(reactor coolant system) in PWR-GALE are based on the data measured from operating reference plants in USA between 1970s and 1980s, it is not proper to apply PWR-GALE to plant of Korea without modification of PWR-GALE. **Fig. 1** shows this fact. As shown **Fig. 1**, the radioactivity distribution of noble gas used in PWR-GALE don't match that from the actual YGN(Young-Gwang Nuclear power plant) 3, 4 unit.

Another code, DAMSAM, is used for estimation of the design basis source term. This code, however, is not easy to access and only have been used for the design basis source term. As above described, at present, the commercial tools are not proper for estimating source term of nuclear power plant of Korea. However, It is necessary to evaluate radionuclide concentration at RCS due to change in RCS conditions such as the fuel defect rate, system parameters to see the overall change in radwaste effluent from the fuel to the environment.

In this study, we selected two methods, use of the model of ANSI/ANS-18.1 and use of ORIGEN 2 code, as the evaluation method for radionuclide concentrations at RCS. The model of ANSI/ANS-18.1 is used in radioactivity of fuel pellet region and coolant region. ORIGEN 2 is used in radioactivity of fuel pellet region. With this method, we have developed the SYCOS to provide a set of radionuclide concentration based on design conditions.

2. Method and Code Description

In this study, the objective plant is the typical PWR in Korea with U-tube steam generator using Zircaloy clad-uranium dioxide fuel. **Fig. 2** shows the system model which are used in ANSI/ANS-18.1-1984. We have selected this system because it is the bases for the removal rate equations and adjustment factors for the different elements along with the design conditions.

The concentration of fission products at RCS is determined by the application of appropriate mathematical removal rate equations and the fission product inventory determined in the two separate regions of the fuel pellet region and the reactor coolant region. The mathematical removal rate equations are obtained by applying mass balance without considering the fuel plenum and gap region. The equation for the fuel pellet region is given as :

$$\frac{dN_i}{dt} = \gamma_i \Sigma_f \Phi - \lambda_i N_i - \sigma_{ai} \Phi N_i \tag{1}$$

The equation for the reactor coolant region is following as ;

$$\frac{dC_i}{dt} = \frac{\nu_i \times \eta_i \times A_i}{WP} - (R_i + \lambda_i + \Sigma_{ai}\Phi) \times C_i(t) - \frac{L_i}{WP} C_i(t) \tag{2}$$

Except some nuclides having a large absorption neutron cross section, and on the assumption of steady state, the **Eq. (2)** is becomes :

$$C_i = \frac{\nu_i \times \eta_i \times A_i}{(R_i + \lambda_i) \times WP} \tag{3}$$

where,

N_i	= concentration of i^{th} nuclide,	[#/cm^3]
γ_i	= fission yield of i^{th} nuclide,	[#/fission]
Σ_f	= macroscopic fission cross section,	[cm^{-1}]
Φ	= thermal neutron flux,	[#/cm^{2}sec]
λ_i	= decay constant,	[sec^{-1}]
σ_{ai}	= absorption cross section of i^{th} nuclide,	[cm^2]
C_i	= concentration of i^{th} fission product in coolant region,	[μCi/cc]
ν_i	= escape rate coefficient,	[sec^{-1}]
η_i	= expected fuel defect rate,	
PF_i	= activitiy of radionuclide at pellet region,	[Ci]
R_i	= radionuclide removal rate in reactor coolant,	[sec^{-1}]
L_i	= leakage or other feed and bleed from the reactor coolant,	[lbm/sec]
WP	= weight of water in reactor coolant system,	[lbs]

In **Fig. 2**, the removal rate of the radionuclide from the system due to demineralization, leakage and etc. is given as :

- For noble gases

$$R_{NG} = \frac{FB + (FD - FB) \times Y}{WP} \tag{4}$$

- For other nuclides

$$R_{other} = \frac{FD \times NB + (1 - NB) \times (FB + FA \times NA)}{WP} \tag{5}$$

where,

$FA=$ flow through the purification system cation demineralizer, [lbs/hr]
$FB=$ reactor coolant letdown flow (yearly average for boron control), [lbs/hr]
$FD=$ Reactor coolant letdown flow(purification), [lbs/hr]
$NA=$ Fraction of material removed in passing through the cation demineralizer
$NB=$ Fraction of material removed in passing through the purification demineralizer
$WP=$ Weight of water in reactor coolant system, [lbs]
$Y=$ Ratio of the total amount of noble gases routed to gaseous radwaste from the purification system to the total amount routed from the primary coolant system to the purification system (not including boron recovery system)

To solve **Eq. (1)**, we selected two cases. One is to use ORIGEN 2. The other is to simplify the **Eq. (1)** with assumption of equilibrium state. ORIGEN 2 is a commercial computer code system for calculating the fission product yields. In case 1, we have acquired the radionuclide concentrations at fuel pellet region through the proper process of results from ORIGEN 2. In case 2, we have assumed the equilibrium state. As the concentrations at RCS is maximum at equilibrium state, it is very conservative assumption except some radionuclides with a large neutron absorption cross section.

3. Results and Discussion

We have applied the above described method to YGN3, 4 and developed SYCOS with Visual Basic as shown in **Fig. 2**, which shows a input window of code. This code can provide radionuclide concentrations at the primary and secondary coolant systems and use above described two methods to solve the differential equation at fuel pellet region. Database to use results from ORIGEN2 are provided to SYCOS. With SYCOS, Sample runs to calculate concentration of noble gas at YGN 3, 4 was carried out. **Table 1** presents the operation parameters of YGN 3, 4 which is used for calculation. These parameters are chosen as being reasonably representative of the design to which the standard is applicable.

We have compared the results from the SYCOS with the actual data of noble gas concentrations at fourth fuel cycle. The two results based on SYCOS are shown from **Fig. 3** to **Fig. 7**. In **Fig. 3**, the radioactivity distribution of noble gas are very similar to that of the actual data except for Xe-133 and Xe-135. SYCOS is not able to cover these nuclides, because of their a large neutron absorption cross section. **Fig. 4** shows the concentrations due to change of the fuel failure rate from 0.08% to 1%. The fuel failure rate is the predominant factor at determining the concentrations in RCS. Although the actual fuel failure rate is unknown, for variation from 0.05% to 0.12% of fuel defect rate, the results from SYCOS are similar to the actual data. Especially, In using the equilibrium, the resultant values with various ranges, from 0.08% to 0.12% of fuel failure rate, are the same as the actual values. Through this, we can guess the fuel defect rate. Therefore, with more sufficient data related to fuel failure rate and modification of evaluation code, the fuel failure rate with the radionuclides concentration at RCS is able to be guessed.

Also, as shown in **Fig. 5**, SYCOS is able to provide two kinds of results. Although the results in using ORIGEN 2 is more larger than those in using a simplified equation, the radioactivity distributions of two kinds are similar except to each other for Xe-133. Although Xe-133 has a small fission yield, the radioactivity of Xe-133 is large because of a short half-life of Xe-133m. Therefore, using a simplified equation based on fission yield is not proper for Xe-133. **Fig. 6** and **Fig. 7** show the results carefully. In **Fig. 6**, the fuel defect rate have the range from 0.12% to 0.05% and **in Fig. 7** have the range from 0.08% to 0.05%. The various fuel defect rate is because the results in using ORIGEN 2 have a wild range values.

The SYCOS has a few limitations. First, it is difficult to predict the concentration of some radionuclides with a large neutron absorption cross section. Because the behavior of those radionuclides can not be evaluated with **Eq. (3)**, the radionuclide with a large neutron absorption cross section is out of the model. In **Fig. 8**, the two results from the SYCOS is not coincided. Second, the SYCOS requires a large database for concentration at pellet region to solve **Eq (1)**. On the assumption of equilibrium fuel cycle, the required database can be decreased. Third, the SYCOS don't treat the corrosion production model because the corrosion production mechanism is very complex. For these limitations, the SYCOS are modified by adding the simplified equation of corrosion product.

Although these limitations, the SYCOS can be a useful tool to evaluate the concentration of radionuclide at RCS because, at present, the commercial tools such for this purpose don't match that of Korea. SYCOS is able to theoretically calculate the radionuclide concentration at RCS, while the these tools use the actual data. Therefore, if we build the database of design conditions, we can apply SYCOS to the plant of Korea.

4. Conclusion

It is necessary to calculation the source term due to the change of plant design conditions. At present, the commercial tools used for this purpose are based on the actual data measured before 1980s and it is not easy to access. In this study, the evaluation method for estimation of source term is suggested and the SYCOS is provided as a calculation tool. The SYCOS is able to calculate the concentrations of radionuclide at RCS for change of nuclear power plant design conditions.

As a result of applying the SYCOS to YGN 3, 4, we compared the concentration of noble gas at RCS with the actual data. The resultant distribution trend of radioactivity is similar to that of the actual data except for some radionuclides such as Xe-133 and Xe-135. For this study, the fuel defect rate has a range of 0.05%～0.08% in ORIGEN 2 and 0.05%～0.12% in the simplified equation, respectively. Through comparison of the results from SYCOS with the actual data for various of fuel defect rate from 1% to 0.05%, we can guess the fuel defect rate.

Acknowledgement

The authors gratefully acknowledge the financial support of the Korea Institute of Nuclear Safety(KINS).

References

[1] ANS, *Source Term Specification*, 1976

[2] ANS, *Radioactive Source Term for Normal Operation of Light Water Reactors*, 1984

[3] NRC, *Calculation of Release of Radioactive Materials in Gaseous and Liquid Effluents from the Pressurized Water Reactors*, 1985

[4] KINS, *Development of Source Term Evaluation Method for KNGR*, 1988

Table 1. Parameters Used to Describe the Reference Pressurized Water Reactor with U-Tube Steam Generators.

Parameter	Symbol	Units	Nominal Value
Thermal power	P	MWt	2815
Steam flow rate	FS	lbs/hr	12.72×10^6
Weight of water in reactor coolant system	WP	10^3lbs	4.62×10^5
Reactor coolant letdown flow(purification)	FD	L/min	272.5
Reactor coolant letdown flow (yearly average for boron control)	FB	L/min	1.82
Steam generator blowdown flow(total)	FBD	10^3lbs	130.0
Fraction of radioactivity in blowdown steam which is not returned to the secondary coolant system.	NBD	-	
Flow through the purificaiton system cation demineralizer	FA	gpm	0.0
Ratio of condensate demineralizer flow rate to the total steam flow rate	NC	-	
CVCS Gas Stripper Removal Efficiency	Y	-	

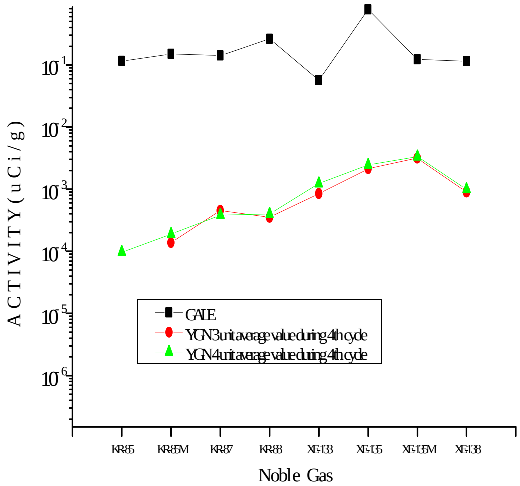

Figure 1. Comparison of PWR-GALE with operating data of YGN 3, 4.

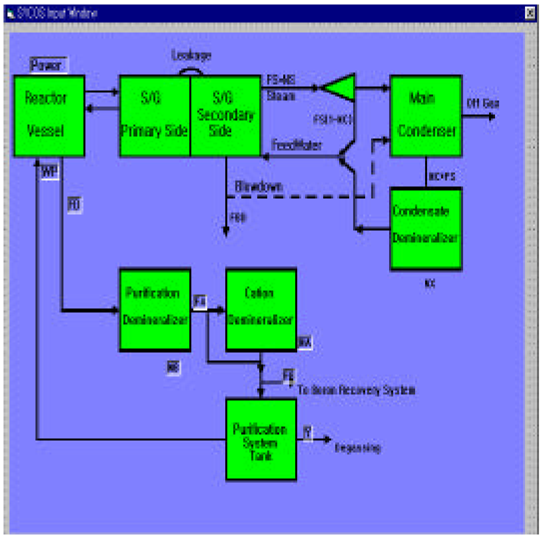

Figure 2. Radionuclide Removal Paths for PWR with U-Tube Steam Generator.

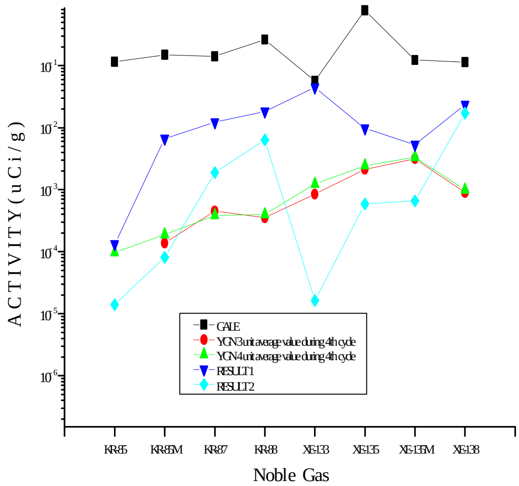

Figure 3. Comparison of results with the measured data.
Result 1 : ORIGEN 2, 0.12% fuel defect rate
Result 2 : the simplified equation, 0.12% fuel defect rate

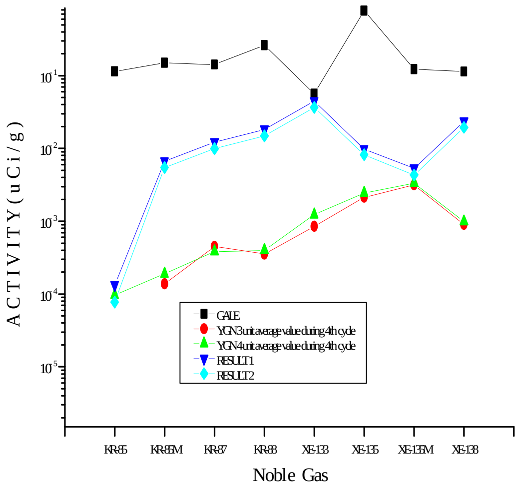

Figure 4. Comparison of results with the measured data.
Result 1 : ORIGEN 2, 1% fuel defect
Result 2 : ORIGEN 2, 0.12% fuel defect

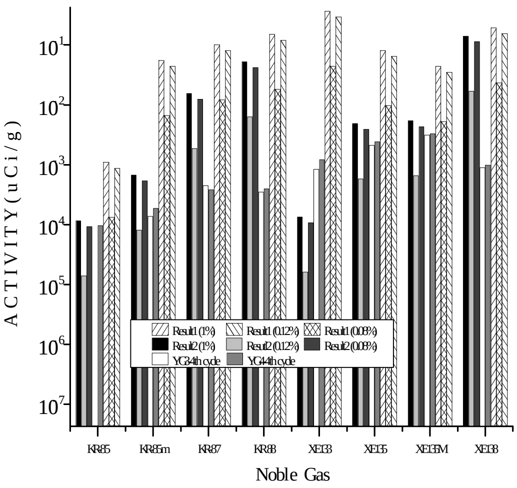

Figure 5. Results of the SYCOS based on change of fuel defect rate.

Result 1 : ORIGEN 2

Result 2 : a simplified equation

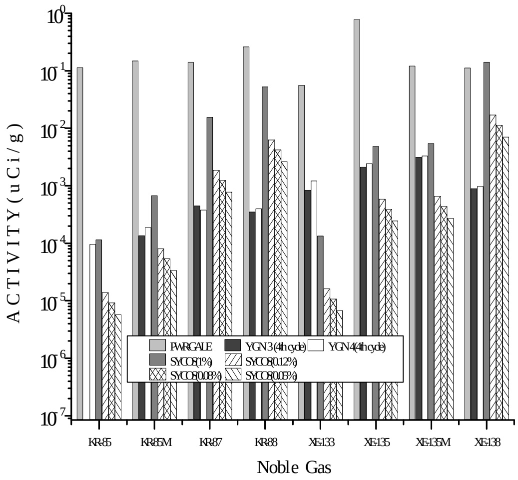

Figure 6. Comparison of the results with the actual data. (Using ORIGEN 2)

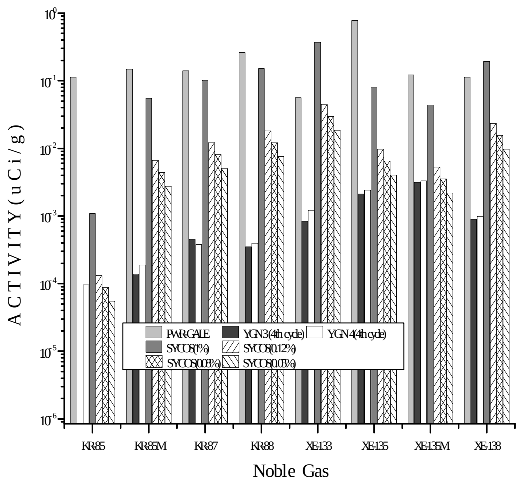

Figure 7. Comparison of the results with the actual data. (Using the simplified equation)

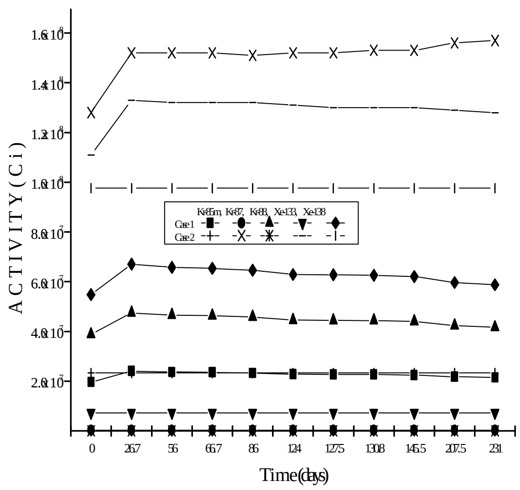

Figure 8. Concentrations at Fuel pellet region from the SYCOS.

Case 1 : ORIGEN 2

Case 2 : the simplified equation