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A Source Term Calculation for the APR1400 NSSS Auxiliary System Components Using the Modified SHIELD Code

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1. Introduction

The SHIELD code [1] has been used to calculate the source terms of NSSS Auxiliary System (comprising CVCS, SIS, and SCS) components of the OPR1000. Because the code had been developed based upon the SYSTEM80 design and the APR1400 NSSS Auxiliary System design is considerably changed from that of SYSTEM80 or OPR1000, the SHIELD code cannot be used directly for APR1400 radiation design. Thus the hand-calculation is needed for the portion of design changes using the results of the SHIELD code calculation.

In this study, the SHIELD code is modified to incorporate the APR1400 design changes and the source term calculation is performed for the APR1400 NSSS Auxiliary System components.

2. Code Modification and Sample Calculation

The SHIELD code is written in FORTRAN computer programming language and runs on HP-9000 series work station using HP-UX 9.0 Operating System or IBM Personal Computer using Windows 98 Operating System. The code is composed of a main program and 12 subroutines. Each subroutine is used to calculate the component influent specific activities, radioactive nuclide inventories, and γ radio-activities per energy group of the corresponding system, except for the input and output subroutines.

2.1 SHIELD Code Modification

The items incorporated in the SHIELD code for the APR1400 design are as follows:

a. Add the boric acid storage tank (BAST) and in-containment refueling water storage tank (IRWST), and remove the refueling water tank (RWT)
b. Model four(4) safety injection pumps instead of two(2) high pressure safety injection (HPSI) pumps and two(2) low pressure safety injection (LPSI) pumps
c. Add the shutdown cooling pump (SCP) and SCP mini-flow heat exchanger
d. Add auxiliary charging pump (ACP), charging pump mini-flow heat exchanger (MFHX), and boric acid concentrator (BAC) concentrate transfer pump
e. Add the new model for the volume control tank (VCT) to optimize the VCT source terms using the stripping fraction (Φ) defined as follows:

$$\Phi = 1 - \left[\frac{K \cdot Q}{K \cdot Q + \lambda \left(K \cdot L + V_V \right) + P} \right] \quad (1)$$

where
$$K = \frac{R \cdot T}{M \cdot H} \quad (2)$$

R = gas constant,
T = VCT operating temperature,
M = molecular weight of water,
H = Henry's constant,
Q = letdown flow rate,
λ = decay constant of nuclide,
L = VCT liquid volume,
V_V = VCT vapor volume, and
P = VCT purge rate.

f. Revise the calculation method of the noble gas activities in the spent fuel pool water
g. Add the calculation model of the activities of crud deposited in heat exchangers
h. Add the calculation model of the gaseous specific activities transferred from the CVCS to the Gaseous Radwaste System (GRS)
i. Add the calculation model of the post-LOCA radioactivity inventories in the components of the SIS and SCS
j. Add the new chemical form to deal with tritium
k. Include the secular equilibrium of Cs-137 and Ba-137m

The above items reflect not only the APR1400 design changes (i.e., items a, b, and c) but also the OPR1000 design changes since SYSTEM80 (i.e., item d) and facilitate the automatic calculation instead of hand-calculations (i.e., Items e through k).

The HPSI and LPSI pumps of the OPR1000 take suction from the RWT in the injection mode and the containment sump in the recirculation mode, but the safety injection pumps of the APR1400 take suction from the IRWST only during and following a LOCA.

The modified SHIELD code is also composed of a main program and 12 subroutines and the function of each subroutine is the same as that of the original SHIELD code.

2.2 Sample Calculation

The sample calculations are performed by running the modified SHIELD code upon HP-9000 series work station and IBM Personal Computer. The design data of APR1400 with the core power of 3,983 MWth are inputted to the modified code [2]. It is conservatively assumed that the core power is 4,063 MWth by applying 102% power requirement, the fuel cladding of 0.25% is failed, and the CVCS gas stripper is not operating.

3. Calculation Results

The results of sample calculations are compared with those of hand-calculations as shown in Tables 1 through 8. Though the calculations are performed for 57 radioactive nuclides, 18 γ-ray energy groups, and 7 decay times, the tables show the results for several representative nuclides, γ-ray energy groups, and decay times.

Tables 1 through 7 show that the results of code calculation agree well with those of hand-calculation. In Table 8 the code calculation results are compared with WEC Radiation Analysis Manual [3] for verification of the new VCT model, and they are in good agreement.

Table 1. Radioactivity inventories in BAST and IRWST (Bq)

a. BAST

Nuclide	Code Cal	Hand-Cal	Nuclide	Code Cal	Hand-Cal
Kr-85	1.9E+08	1.9E+08	Co-60	3.7E+08	3.7E+08

b. IRWST

Nuclide	Code Cal	Hand-Cal	Nuclide	Code Cal	Hand-Cal
Kr-85	2.1E+10	2.1E+10	Co-60	8.0E+08	8.0E+08

Table 2. Post-LOCA γ activity inventories in safety injection pump and shutdown cooling pump (γ/sec)

a. Safety injection pump

Decay Time / E(MeV)	Code Cal		Hand-Cal	
	10 hr	100 hr	10 hr	100 hr
3.0E-01	2.79E+14	1.87E+14	2.79E+14	1.87E+14
5.5E+00	2.39E+06	6.82E-04	2.39E+06	6.81E-04

b. Shutdown cooling pump

Decay Time / E(MeV)	Code Cal		Hand-Cal	
	10 hr	100 hr	10 hr	100 hr
3.0E-01	2.72E+14	1.82E+14	2.72E+14	1.82E+14
5.5E+00	2.32E+06	6.64E-04	2.32E+06	6.63E-04

Table 3. Radioactivity inventories in SCP MFHX (Bq)

Nuclide	Code Cal	Hand-Cal	Nuclide	Code Cal	Hand-Cal
Kr-85	4.4E+09	4.3E+09	Co-60	2.2E+06	2.2E+06
Xe-135	6.5E+09	6.3E+09	Cs-137	3.8E+08	3.8E+08
I-131	2.6E+09	2.6E+09	Ba-137m	3.8E+08	3.8E+08

Table 4. Radioactivity inventories in ACP, charging pump MFHX, and BAC concentrate transfer pump (Bq)

a. ACP

Nuclide	Code Cal	Hand-Cal	Nuclide	Code Cal	Hand-Cal
Kr-85	2.3E+05	2.3E+05	Co-60	2.6E+04	2.6E+04

b. Charging pump MFHX

Nuclide	Code Cal	Hand-Cal	Nuclide	Code Cal	Hand-Cal
Kr-85	8.8E+05	8.8E+05	Co-60	9.9E+04	1.0E+05

c. BAC concentrate transfer pump

Nuclide	Code Cal	Hand-Cal	Nuclide	Code Cal	Hand-Cal
Kr-85	2.1E+03	2.0E+03	Co-60	4.3E+03	4.3E+03

Table 5. Noble gas specific activities in fuel pool (Bq/cm^3)

Nuclide	Code Cal	Hand-Cal	Nuclide	Code Cal	Hand-Cal
Kr-85	4.4E+02	4.4E+02	Xe-133	2.4E+04	2.4E+04
Kr-88	7.7E-03	7.7E-03	Xe-135	3.2E+01	3.2E+01

Table 6. Activities of crud deposited in heat exchangers (γ/sec)

Energy (MeV)	Code Cal		Hand-Cal	
	RGHX	LDHX	RGHX	LDHX
0.25	4.0E+10	7.8E+09	4.0E+10	7.8E+09
0.75	1.8E+11	3.6E+10	1.8E+11	3.6E+10
1.38	5.9E+09	1.2E+09	5.9E+09	1.2E+09

Table 7. Gaseous specific activities transferred from gas stripper (GS) and RDT to GRS (Bq/cm^3)

Nuclide	Code Cal		Hand-Cal	
	From GS	From RDT	From GS	From RDT
H-3	1.7E+01	1.0E+01	1.7E+01	1.0E+01
Kr-85	1.4E+06	3.7E+04	1.4E+06	3.7E+04
Xe-135	2.6E+06	5.4E+04	2.6E+06	5.4E+04
I-131	8.2E+00	2.4E+01	8.2E+00	2.4E+01

Table 8. VCT specific activities using new model (μCi/cm^3)

Nuclide	Code Cal		WEC RAM Results	
	Liquid	Vapor	Liquid	Vapor
Kr-88	1.3	29	1.3	30
Xe-133	250	3800	250	3800
Cs-134	1.8	-	1.8	-
Rb-88	4.7	-	4.7	-

4. Conclusions

The SHIELD code is modified to incorporate the APR1400 NSSS Auxiliary System design changes. The results of the code calculation for the core power of 3,983 MWth are compared with those of the hand-calculation. The comparison demonstrates that two results are in good agreement. It is concluded that the modified SHIELD code is validated, and thus can be used to calculate the source terms of the APR1400 NSSS Auxiliary System components for the shielding design. The modified code also provides the saving on time and effort and increase of the calculation accuracy.

REFERENCES

[1] Computer Code Description for the SHIELD Code, Version 01, WEC, May 1977

[2] SKN 3&4 Preliminary Safety Analysis Report, Sections 9.3.4, 11.1, and 12.2, KHNP

[3] Radiation Analysis Manual, Rev. 2, WEC, Dec. 1978.