REVISED RESPONSE TO REQUEST FOR ADDITIONAL INFORMATION

APR1400 Design Certification

Korea Electric Power Corporation / Korea Hydro & Nuclear Power Co., LTD

Docket No. 52-046

RAI No.:	**343-8420**
SRP Section:	**12.02 - Radiation Sources**
Application Section:	**12.2**
Date of RAI Issue:	**12/22/2015**

Question No. 12.02-23

This is a follow-up to RAI 8090, Question 12.02-13.

Requirement

10 CFR 52.47(a)(5) requires that the FSAR contain the kinds and quantities of radioactive materials expected to be produced in the operation and the means for controlling and limiting radioactive effluents and radiation exposures within the limits set forth in 10 CFR 20.

Issue

In the response to Question 12.02-13, the applicant indicates that source terms for components are conservative because the RCS source term is based on five cycle operation. However, the applicant provides no justification for why this is conservative. Past staff experience with previous applications indicates that typically RCS activity reaches near equilibrium value after several months of operation and would not be expected to change significantly after that time (with fuel leakage and operating conditions staying the same, the RCS concentrations of most radionuclides are constant). Therefore, it is unclear why assuming five cycle operation is conservative. No justification is provided why it is conservative, versus normal fuel replacement.

In addition, the applicant indicated that the nuclides selected in the source terms in FSAR Chapters 11 and 12 are consistent with the nuclides included in ANSI/ANS 18.1. As indicated in the SRP, it is acceptable to only consider the nuclides listed in ANSI/ANS 18.1 (as well as it is acceptable to consider the additional nuclides in those source associated with the liquid waste management system, because the DIJESTER code considers the additional nuclides).

However, the applicant indicates that only the DIJESTER code considers the buildup of radioactive daughters (besides Ba-137m, which is acceptably considered to have the same activity as Cs-137 in all sources, except for in the Steam Generator Blowdown, Condensate Polishing System, and Spent Fuel Pool Demineralizer source terms). Therefore, in the other source terms downstream of the RCS, some of the nuclide activity values listed do not provide an accurate estimation of the nuclide concentrations. Staff review indicates that the buildup of some the daughter products in some components may be significant to some of the gamma source terms in the plant (and therefore, the shielding and zoning for those components). For example, for the gaseous waste management system components, the accumulation of Rb-88 from the decay of Kr-88 would likely provide a difference in the gamma dose rates from those components. Staff analysis indicates that the daughters of noble gasses (mostly Rb-88) listed in ANSI/ANS 18.1 may contribute nearly 20% to the source terms of the guard beds and the delay beds. In addition, the decay of Te-132 to I-132, would significantly increase I-132 activity in many components. There are several other radionuclides listed in ANSI/ANS 18.1 which would also impact source terms, to a lesser extent.

SRP 12.2 indicates that the buildup of radionuclides in components and systems should be addressed. Part of the buildup in components is from daughters generated in the decay of parents. Therefore, update the source terms and plant shielding and zoning, as appropriate, to include the contribution of daughter radionuclides for daughters listed in ANSI/ANS 18.1 (including for Ba-137m in the Steam Generator Blowdown, Condensate Polishing System, and Spent Fuel Pool Demineralizer source terms in Tables 12.2-18 and 12.2-17a), or provide additional detailed justification for why due to the RCS activity source terms are already more conservative than they would be if the contribution of daughters was included.

Response – (Rev. 3)

(Note: Responses to NRC comments on Rev. 1 provided on April 4, 2017, and Rev. 2 provided on August 1, 2017, are included in this Revision)

1. Assumption of Five Cycle Operation

   Based on the calculation of RCS source term, most of the fission products and their daughters reach their equilibrium activity level within one fuel cycle. However, several of the long-lived nuclides (e.g. Kr-85, Sr-90, Cs-134, Cs-137) may not reach equilibrium before the fourth or fifth fuel cycle. Therefore, in order to insure maximum reactor coolant activities the computer modeling code (DAMSAM) is configured to run for four equilibrium fuel cycles, assuming no leakage or load maneuvering waste from the primary coolant. After the simulation of four equilibrium cycles, the maximum activity of each nuclide appearing in the RCS during fifth cycle is taken as the reactor coolant equilibrium concentration shown in DCD Table 12.2-5 in order to conservatively calculate the activities for nuclides that take a long time to reach the equilibrium level. For this reason, the duration of reactor operation is set at five fuel cycles as the basis for reactor coolant source term calculations (DCD Table 11.1-1). Table 1 shows the maximum atomic populations of the fission products in each cycle in the DAMSAM calculation for five cycles. As shown in this table, the maximum atomic populations such as Cs-134 and Cs-137 continuously increase up to fifth cycle.

   The number of APR1400 equilibrium core batches for 18-month cycle is designed to be three or less. Thus, the DAMSAM results considering five equilibrium cycles are more conservative than the actual operation. In particular, it is conservative for Cs-137, which decay to Ba-137m, the most significant daughter nuclide from a radiation shielding design.

The APR1400 cycle length used by DAMSAM is 18 months, of which the power operation period at full power is 480 days (480 Effective Full Power Days) and the remainder is downtime. A more detailed clarification regarding the APR1400 cycle length (18 months vs 480 days) is provided in Attachment 7.

Table 1 Maximum Atomic Populations of Fission Products in Each Cycle

(Unit : atoms)

Cycle	Kr-85		Sr-90		Cs-134		Cs-137	
	Fuel	Coolant	Fuel	Coolant	Fuel	Coolant	Fuel	Coolant
1st	2.591E+24	4.373E+21	1.704E+26	2.558E+17	7.163E+24	2.595E+19	2.451E+26	8.903E+20
2nd	2.722E+24	6.224E+21	3.052E+26	4.554E+17	1.610E+25	5.845E+19	3.584E+26	1.309E+21
3rd	2.729E+24	6.326E+21	4.118E+26	6.133E+17	2.172E+25	7.908E+19	4.107E+26	1.507E+21
4th	**2.729E+24**	**6.331E+21**	4.960E+26	7.381E+17	2.470E+25	9.024E+19	4.349E+26	1.600E+21
5th	2.729E+24	6.331E+21	**5.626E+26**	**8.368E+17**	**2.616E+25**	**9.575E+19**	**4.461E+26**	**1.643E+21**

2. Effects of Daughter Products Buildup in RCS and CVCS

In order to estimate the effects on the buildup of the daughter products in the RCS and CVCS component radiation source terms, the methodology of DAMSAM/SHIELD-APR code system and the conservatism included in the results were reviewed in several ways. This review demonstrated that the conservatisms in the results of DAMSAM/SHIELD-APR code system are substantially larger than the effect of the non-modeled contribution of daughter products in the calculation of the RCS and CVCS component source terms. The detailed review and its conclusions was provided in the report of “Response to RAI 12.02-23, DAMSAM/SHIELD-APR Code Methodology – Daughter Product Issue”, LTR-REA-17-8 (February 10, 2017) [ML17068A172].

For the Boric Acid Condensate Ion Exchanger (BACIX) and Gas Stripper/Overhead Condenser (GSP/GSOC), a review of the effect of the buildup of daughter nuclides for each component was performed. The results of this review are summarized below.

a. Boric Acid Condensate Ion Exchanger (BACIX)

KHNP will increase the shielding source term of the BACIX (DCD Table 12.2-11), as shown in Attachment 6, to cover the potential non-conservatism of not including the accumulation of daughter nuclides. Based on the subsequent analysis of increasing the BACIX source term, there is no change in the radiation zones or change in the shielding design.

The revised inventories of the nuclides in Attachment 6 include the SHIELD-APR results and the contribution from the parent decay. For conservative calculations, assuming that the activities of all Te and I radionuclides would reach equilibrium with those of their parents, the activities from just parent decay in the BACIX can be calculated by the following simple formula.

$$A_j^{Parent} = \Sigma_i A_i^{Total} f_{i\to j}$$

Where,

A_j^{Parent} is the activity of the nuclide j from just its parent decay,

A_i^{Total} is the total activity of the nuclide i, which is the sum of SHIELD-APR results and contribution from the parent decay,

$f_{i\to j}$ is the branching fraction for the nuclide i → j decay.

The results are summarized in the following table.

Nuclide	$f_{i\to j}$ (Parent : Fraction)	SHIELD-APR Results (Bq)	A_j^{Parent} (Bq)	Total (A_j^{Total}) (Bq)
Te-129m	-	1.9E+05	-	1.9E+05
Te-129	Te-129m : 0.63	8.1E-01	1.20E+05	1.2E+05
Te-131m	-	2.5E+03	-	2.5E+03
Te-131	Te-131m : 0.222	1.9E-01	5.55E+02	5.6E+02
Te-132	-	1.3E+05	-	1.3E+05
I-131	Te-131m : 0.778 Te-131 : 1.0	9.3E+06	2.51E+03	9.3E+06
I-132	Te-132 : 1.0	3.5E+02	1.30E+05	1.3E+05

b. Overhead Condenser (and Gas Stripper Package)

The effect of the buildup of daughter nuclides in the source term of the GSOC was determined to be negligible, mainly due to the relatively short ‘buildup time’ in the GSOC. In addition, the GSP source term is determined to have additional margin due to the increase in model volume. Therefore, the conservatism of the GSP/GSOC source terms and related shielding design is estimated to exceed the effect that does not consider the buildup of daughter nuclides in the source term. The detailed review for the GSP/GSOC is provided in Attachment 7.

3. Effects of Daughter Products Buildup in BOP systems

KHNP performed a review of the source term for the shielding calculations of BOP systems, such as the Steam Generator Blowdown (SGBD), Condensate Polishing System (CPS), and Spent Fuel Pool Cooling and Clean up System (SFPCCS), and evaluated the impact of the daughter nuclides on dose rate based on the comparison of the shielding calculation results. The evaluation for the Gaseous Radwaste System (GRS) will be provided in the response to RAI 343-8420, Question No. 12.02-25.

This evaluation is divided into two parts; the source term analysis and the shielding analysis. In the source term analysis, KHNP calculated the daughter nuclide build-up for BOP systems using the modified balance equations for source terms. The daughter nuclides considered in this evaluation are the fourteen radionuclides listed in ANSI/ANS 18.1. One level decay from the parent nuclide is assumed. The detailed explanation of the decay cases considered for the production of daughter nuclides is included in Attachment 1. The detailed balance equations for daughter nuclide build-up for each of the BOP system components are also included in Attachment 1.

Using the results of the source term analysis considering the daughter nuclide build-up activity, the shielding analyses were reevaluated to determine dose rates and radiation zones for BOP cubicles and areas.

The impact of the daughter nuclides build-up is evaluated based on the comparison of the reevaluation shielding calculation results to the original shielding calculation results, which were based on input source terms that did not consider daughter nuclide build-up. Also, an additional shielding calculation is performed to demonstrate the impact of Ba-137m build-up, as Ba-137m is the only daughter nuclide whose build-up was shown to be significant for the primary system source term calculation.

As shown in Table 2, dose rates for the SGBD and SFPCCS increased up to 1.7% from the original dose rate calculation result, due to the inclusion of the daughter nuclides build-up. The dose rate increase for the SGBD and SFPCCS are significantly less than those for CPS because the Ba-137m activity is already assumed to be the same as Cs-137 activity in the original shielding calculations as shown in Attachment 2.

The dose rates for CPS mixed bed increased up to 4.0%, and that for CPS cation bed increased up to 25.6%. The daughter nuclide build-up in the CPS cation bed has an apparently large impact on the shielding analysis because the cation source term consists of a relatively small number of nuclides. However, it is found that the radiation zone for the condensate polishing area (073-T03), where CPS mixed and cation beds are located, remains zone 2, even considering the increased dose due to the added daughter nuclide build-up activity in both CPS mixed and cation beds.

Also, it is found that the dominant contributing daughter nuclide for the dose rate increase is caused by Ba-137m, and the impact of other daughter nuclides on the dose rate is so small as to be negligible, considering the conservative assumptions and margins contained in the original shielding analysis.

KHNP will update the source term for BOP systems including Ba-137m build-up only as shown in Attachment 3. This approach is consistent with the source term analysis for the primary system components.

Table 2 Shielding Analysis Results

Component	Contact Dose Rates (mSv/hr)		
	w/o DNs	w/ Ba-137m only	w/ all DNs
SGBD Demineralizer	8.330E+01	8.330E+1	8.453E+01 (+1.5%)

SGBD Flash Tank	7.158E-01	7.160E-01 (+0.03%)	7.161E-01 (+0.04%)
CPS Cation Bed	1.812E-03	2.268E-03 (+25.2%)	2.276E-03 (+25.6%)
CPS Mixed Bed	1.362E-02	1.411E-02 (+3.5%)	1.417E-02 (+4.0%)
SFPCCS Demineralizer	3.703E+01	3.703E+01	3.769E+01 (+1.7%)

Note: DN refer to daughter nuclide.

4. Effects of Daughter Products Buildup in Solid Waste Management System

KHNP preformed a review of the source terms for solid waste management system (SWMS), and found that the daughter nuclide buildup has insignificant impact on the SWMS. Detailed information for the source term evaluations for the SWMS is provided in Attachment 4.

5. Shielding for Pipe Lines

The source terms for the outflow pipe lines are determined using the volume ratio of the outflow pipe line to the upstream component. Conservative assumptions accounting for design characteristics of the systems are applied in the determination of pipe line source terms. Specific examples are provided in Attachment 5 to demonstrate the methodology used for the shielding analysis for the piping area.

Impact on DCD

DCD Tables 11.1-6, 11.1-10, 12.2-17a and 12.2-18 will be revised as indicated in Attachment 3.
DCD Table 12.2-11 will be revised as indicated in Attachment 6.

Impact on PRA

There is no impact on the PRA.

Impact on Technical Specifications

There is no impact on the Technical Specifications.

Impact on Technical/Topical/Environmental Reports

There is no impact on any Technical, Topical, or Environmental Report.

Source Term Analysis Considering Additional Daughter Nuclides

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Table 11.1-6

Design Basis Radionuclide Concentrations (1)
in the Secondary System (1% Fuel Defect)

Nuclide	Steam Generator			
	Liquid		Steam	
	(μCi/g)	(Bq/g)	(μCi/g)	(Bq/g)
Kr-85m	-	-	1.00E-05	3.71E-01
Kr-85	-	-	2.48E-07	9.16E-03
Kr-87	-	-	9.76E-06	3.61E-01
Kr-88	-	-	2.48E-05	9.16E-01
Xe-131m	-	-	2.48E-06	9.16E-02
Xe-133m	-	-	6.43E-07	2.38E-02
Xe-133	-	-	3.22E-04	1.19E+01
Xe-135m	-	-	7.65E-06	2.83E-01
Xe-135	-	-	4.35E-05	1.61E+00
Xe-137	-	-	1.86E-06	6.87E-02
Xe-138	-	-	6.57E-06	2.43E-01
Br-84	8.19E-06	3.03E-01	8.19E-08	3.03E-03
I-131	3.24E-03	1.20E+02	3.24E-05	1.20E+00
I-132	5.86E-04	2.17E+01	5.86E-06	2.17E-01
I-133	4.38E-03	1.62E+02	4.38E-05	1.62E+00
I-134	2.39E-04	8.86E+00	2.39E-06	8.86E-02
I-135	2.18E-03	8.08E+01	2.18E-05	8.08E-01
Rb-88	5.22E-04	1.93E+01	2.61E-06	9.64E-02
Cs-134	5.16E-04	1.91E+01	2.58E-06	9.56E-02
Cs-136	6.89E-05	2.55E+00	3.46E-07	1.28E-02
Cs-137	5.97E-04	2.21E+01	3.00E-06	1.11E-01
Cr-51	1.83E-05	6.78E-01	9.16E-08	3.39E-03
Mn-54	2.12E-06	7.85E-02	1.06E-08	3.93E-04
Fe-55	1.59E-06	5.88E-02	7.95E-09	2.94E-04
Fe-59	3.97E-07	1.47E-02	1.99E-09	7.36E-05
Co-58	6.08E-06	2.25E-01	3.05E-08	1.13E-03
Co-60	7.03E-07	2.60E-02	3.51E-09	1.30E-04
Zr-95	8.03E-07	2.97E-02	4.03E-09	1.49E-04
Zn-65	6.76E-07	2.50E-02	3.38E-09	1.25E-04

Nuclide	Steam Generator			
	Liquid		Steam	
	(μCi/g)	(Bq/g)	(μCi/g)	(Bq/g)
N-16	1.99E-05	7.38E-01	9.97E-08	3.69E-03
Na-24	5.62E-05	2.08E+00	2.81E-07	1.04E-02
Sr-89	4.35E-06	1.61E-01	2.17E-08	8.04E-04
Sr-90	2.97E-07	1.10E-02	1.49E-09	5.50E-05
SR-91	5.76E-06	2.13E-01	2.86E-08	1.06E-03
Y-91m	1.57E-06	5.81E-02	7.86E-09	2.91E-04
Y-91	6.32E-07	2.34E-02	3.16E-09	1.17E-04
Y-93	1.34E-07	4.95E-03	6.68E-10	2.47E-05
Nb-95	6.81E-07	2.52E-02	3.41E-09	1.26E-04
Mo-99	3.65E-04	1.35E+01	1.83E-06	6.76E-02
Tc-99M	1.87E-04	6.93E+00	9.35E-07	3.46E-02
Ru-103	2.35E-07	8.70E-03	1.18E-09	4.35E-05
Ru-106	1.01E-07	3.72E-03	5.03E-10	1.86E-05
Ag-110m	1.72E-06	6.38E-02	8.62E-09	3.19E-04
Te-129m	7.92E-06	2.93E-01	3.97E-08	1.47E-03
Te-129	4.24E-06	1.57E-01	2.12E-08	7.84E-04
Te-131m	3.57E-05	1.32E+00	1.79E-07	6.62E-03
Te-131	4.00E-06	1.48E-01	1.99E-08	7.38E-04
Te-132	2.56E-04	9.49E+00	1.28E-06	4.74E-02
Ba-137m	~~1.87E-05~~ 5.97E-04	~~6.92E-01~~ 2.21E+01	~~9.35E-08~~ 3.00E-06	~~3.46E-03~~ 1.11E-01
Ba-140	5.30E-06	1.96E-01	2.65E-08	9.81E-04
La-140	1.81E-06	6.69E-02	9.03E-09	3.34E-04
Ce-141	1.98E-07	7.32E-03	9.89E-10	3.66E-05
Ce-143	5.41E-07	2.00E-02	2.70E-09	1.00E-04
Ce-144	5.70E-07	2.11E-02	2.84E-09	1.05E-04
W-187	3.11E-06	1.15E-01	1.55E-08	5.73E-04
Np-239	2.84E-06	1.05E-01	1.41E-08	5.23E-04
H-3	4.57E-01	1.69E+04	4.57E-01	1.69E+04

(1) This source term is used to determine the design basis radioactive source terms for SGBS components.

Table 11.1-10

Expected Radionuclide Concentrations in the Secondary System (1)

Nuclide	Steam Generator Liquid (µCi/g)	Steam Generator Liquid (Bq/g)	Steam Generator Steam (µCi/g)	Steam Generator Steam (Bq/g)
Kr-85m	-	-	2.81E-09	1.04E-04
Kr-85	-	-	2.04E-07	7.54E-03
Kr-87	-	-	2.97E-09	1.10E-04
Kr-88	-	-	3.16E-09	1.17E-04
Xe-131m	-	-	1.54E-07	5.69E-03
Xe-133m	-	-	1.28E-08	4.72E-04
Xe-133	-	-	5.54E-09	2.05E-04
Xe-135m	-	-	2.27E-08	8.41E-04
Xe-135	-	-	1.18E-08	4.37E-04
Xe-137	-	-	5.92E-09	2.19E-04
Xe-138	-	-	1.07E-08	3.95E-04
Br-84	8.86E-08	3.28E-03	8.86E-10	3.28E-05
I-131	3.76E-08	1.39E-03	3.76E-10	1.39E-05
I-132	7.05E-07	2.61E-02	7.05E-09	2.61E-04
I-133	4.54E-07	1.68E-02	4.54E-09	1.68E-04
I-134	7.54E-07	2.79E-02	7.54E-09	2.79E-04
I-135	8.43E-07	3.12E-02	8.43E-09	3.12E-04
Rb-88	7.00E-07	2.59E-02	3.51E-09	1.30E-04
Cs-134	8.19E-10	3.03E-05	4.11E-12	1.52E-07
Cs-136	1.90E-08	7.03E-04	9.51E-11	3.52E-06
Cs-137	1.17E-09	4.33E-05	5.86E-12	2.17E-07
Cr-51	5.78E-08	2.14E-03	2.89E-10	1.07E-05
Mn-54	2.97E-08	1.10E-03	1.49E-10	5.52E-06
Fe-55	2.24E-08	8.28E-04	1.12E-10	4.14E-06
Fe-59	5.59E-09	2.07E-04	2.81E-11	1.04E-06
Co-58	8.57E-08	3.17E-03	4.27E-10	1.58E-05
Co-60	9.89E-09	3.66E-04	4.95E-11	1.83E-06
Zr-95	7.24E-09	2.68E-04	3.62E-11	1.34E-06
Zn-65	9.51E-09	3.52E-04	4.76E-11	1.76E-06

Nuclide	Steam Generator Liquid (µCi/g)	Steam Generator Liquid (Bq/g)	Steam Generator Steam (µCi/g)	Steam Generator Steam (Bq/g)
N-16	5.05E-08	1.87E-03	2.53E-10	9.35E-06
Na-24	7.92E-07	2.93E-02	3.97E-09	1.47E-04
Sr-89	2.61E-09	9.65E-05	1.30E-11	4.82E-07
Sr-90	2.24E-10	8.28E-06	1.12E-12	4.14E-08
Sr-91	1.55E-08	5.72E-04	7.73E-11	2.86E-06
Y-91m	3.43E-09	1.27E-04	1.71E-11	6.33E-07
Y-91	9.70E-11	3.59E-06	4.84E-13	1.79E-08
Y-93	6.81E-08	2.52E-03	3.41E-10	1.26E-05
Nb-95	5.22E-09	1.93E-04	2.61E-11	9.66E-07
Mo-99	1.16E-07	4.30E-03	5.81E-10	2.15E-05
Tc-99m	7.08E-08	2.62E-03	3.54E-10	1.31E-05
Ru-103	1.40E-07	5.17E-03	6.97E-10	2.58E-05
Ru-106	1.68E-06	6.22E-02	8.41E-09	3.11E-04
Ag-110m	2.42E-08	8.97E-04	1.21E-10	4.49E-06
Te-129m	3.54E-09	1.31E-04	1.77E-11	6.54E-07
Te-129	2.12E-07	7.86E-03	1.06E-09	3.93E-05
Te-131m	2.65E-08	9.81E-04	1.32E-10	4.90E-06
Te-131	3.62E-08	1.34E-03	1.81E-10	6.71E-06
Te-132	3.11E-08	1.15E-03	1.55E-10	5.74E-06
Ba-137m	~~3.86E-11~~ 1.17E-09	~~1.43E-06~~ 4.33E-05	~~1.93E-13~~ 5.86E-12	~~7.13E-09~~ 2.17E-07
Ba-140	2.41E-07	8.92E-03	1.21E-09	4.46E-05
La-140	4.49E-07	1.66E-02	2.24E-09	8.28E-05
Ce-141	2.78E-09	1.03E-04	1.40E-11	5.17E-07
Ce-143	4.97E-08	1.84E-03	2.48E-10	9.18E-06
Ce-144	7.43E-08	2.75E-03	3.73E-10	1.38E-05
W-187	4.35E-08	1.61E-03	2.18E-10	8.07E-06
Np-239	3.97E-08	1.47E-03	1.99E-10	7.36E-06
H-3	1.84E-03	6.81E+01	1.84E-03	6.81E+01

(1) This source term is used to determine the expected radioactive source terms and this source terms are presented for information only for SGBS components.

Table 12.2-17a

SFP Demineralizer and Filter Source Terms

Nuclide	Demin. (Bq)	Filter (Bq)	Nuclide	Demin. (Bq)	Filter (Bq)
BR-84	0.00E+00	0.00E+00	RU-106	6.00E+07	0.00E+00
I-131	2.83E+11	0.00E+00	AG-110M	3.39E+09	0.00E+00
I-132	1.96E-23	0.00E+00	TE-129M	1.40E+09	0.00E+00
I-133	1.89E+08	0.00E+00	TE-129	0.00E+00	0.00E+00
I-134	0.00E+00	0.00E+00	TE-131M	1.89E+07	0.00E+00
I-135	1.33E+00	0.00E+00	TE-131	0.00E+00	0.00E+00
RB-88	0.00E+00	0.00E+00	TE-132	5.56E+09	0.00E+00
CS-134	2.78E+11	0.00E+00	BA-137M	~~0.00E+00~~ 3.81E+11	0.00E+00
CS-136	1.33E+10	0.00E+00	BA-140	6.56E+08	0.00E+00
CS-137	3.81E+11	0.00E+00	LA-140	4.51E+06	0.00E+00
NA-24	3.18E+05	0.00E+00	CE-141	3.48E+07	0.00E+00
SR-89	8.80E+08	0.00E+00	CE-143	4.92E+05	0.00E+00
SR-90	3.24E+08	0.00E+00	CE-144	3.14E+08	0.00E+00
SR-91	1.16E+01	0.00E+00	W-187	1.53E+06	0.00E+00
Y-91M	0.00E+00	0.00E+00	NP-239	1.02E+08	0.00E+00
Y-91	2.23E+09	0.00E+00	CR-51	1.22E+10	1.21E+10
Y-93	2.79E+00	0.00E+00	MN-54	4.86E+09	4.88E+09
ZR-95	4.51E+08	4.50E+08	FE-55	5.69E+09	5.71E+09
NB-95	1.25E+08	0.00E+00	FE-59	3.12E+08	3.11E+08
MO-99	5.31E+09	0.00E+00	CO-58	5.59E+09	5.59E+09
TC-99M	4.46E-03	0.00E+00	CO-60	2.82E+09	2.82E+09
RU-103	4.24E+07	0.00E+00	ZN-65	1.30E+09	1.30E+09

Table 12.2-18 (1 of 3)

Steam Generator Blowdown and Condensate Polishing System Source Terms (0.25 % Fuel Defect)

Isotope	SG Water (Bq/g)	SG Steam (Bq/g)	Blowdown Mixed Bed (Bq)	Blowdown Pre-Filter (Bq)	Blowdown Post-Filter (Bq)	Condensate (Bq/g)	CPS Cation Bed (Bq)	CPS Mixed Bed (Bq)	Flash Tank (Bq)
Kr-85m	0.00E+00	1.29E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Kr-85	0.00E+00	5.49E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Kr-87	0.00E+00	1.01E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Kr-88	0.00E+00	2.80E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Xe-131m	0.00E+00	5.49E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Xe-133m	0.00E+00	3.34E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Xe-133	0.00E+00	3.58E+01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Xe-135m	0.00E+00	7.32E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Xe-135	0.00E+00	7.32E-01	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Xe-137	0.00E+00	1.70E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Xe-138	0.00E+00	6.41E-02	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00	0.00E+00
Br-84	7.65E-02	7.65E-04	4.71E+06	0.00E+00	0.00E+00	2.43E-04	0.00E+00	1.28E+05	7.48E+05
I-131	2.99E+01	2.99E-01	6.73E+11	0.00E+00	0.00E+00	9.50E-02	0.00E+00	1.71E+10	2.92E+08
I-132	5.44E+00	5.44E-02	1.46E+09	0.00E+00	0.00E+00	1.73E-02	0.00E+00	3.97E+07	5.32E+07
I-133	4.05E+01	4.05E-01	9.90E+10	0.00E+00	0.00E+00	1.29E-01	0.00E+00	2.70E+09	3.96E+08
I-134	2.16E+00	2.16E-02	2.18E+08	0.00E+00	0.00E+00	6.87E-03	0.00E+00	5.94E+06	2.11E+07
I-135	2.08E+01	2.08E-01	1.63E+10	0.00E+00	0.00E+00	6.61E-02	0.00E+00	4.44E+08	2.03E+08
Rb-88	5.96E+00	2.98E-02	2.06E+08	0.00E+00	0.00E+00	1.36E-02	4.00E+06	4.00E+05	5.83E+07

Replace these columns with "A"

RAI 343-8420 - Question 12.02-23_Rev.1

Table 12.2-18 (2 of 3)

Isotope	SG Water (Bq/g)	SG Steam (Bq/g)	Blowdown Mixed Bed (Bq)	Blowdown Pre-Filter (Bq)	Blowdown Post-Filter (Bq)	Condensate (Bq/g)	CPS Cation Bed (Bq)	CPS Mixed Bed (Bq)	Flash Tank (Bq)
Cs-134	4.77E+00	2.39E-02	1.55E+12	0.00E+00	0.00E+00	1.08E-02	5.27E+08	5.63E+08	4.67E+07
Cs-136	6.50E-01	3.25E-03	2.36E+10	0.00E+00	0.00E+00	1.48E-03	6.65E+07	3.75E+07	6.35E+06
Cs-137	5.52E+00	2.76E-02	1.94E+12	0.00E+00	0.00E+00	1.25E-02	6.10E+08	6.61E+08	5.40E+07
Cr-51	6.78E-01	3.39E-03	5.20E+10	4.73E+10	4.73E+08	1.54E-03	7.23E+07	5.60E+07	9.87E+08
Mn-54	7.85E-02	3.93E-04	2.28E+10	2.07E+10	2.07E+08	7.14E-05	3.46E+06	3.63E+06	5.94E+10
Fe-55	5.88E-02	2.94E-04	1.95E+10	1.77E+10	1.77E+08	5.35E-05	2.60E+06	2.79E+06	6.80E+09
Fe-59	1.47E-02	7.36E-05	1.73E+09	1.57E+09	1.57E+07	1.34E-05	6.37E+05	5.57E+05	6.89E+10
Co-58	2.25E-01	1.13E-03	3.71E+10	3.37E+10	3.37E+08	2.05E-04	9.82E+06	9.28E+06	8.52E+09
Co-60	2.60E-02	1.30E-04	8.90E+09	8.09E+09	8.09E+07	2.36E-05	1.15E+06	1.24E+06	1.07E+09
Zr-95	1.91E-02	9.53E-05	2.96E+09	2.69E+09	2.69E+07	2.70E-05	1.29E+06	1.21E+06	8.03E+08
Zn-65	2.50E-02	1.25E-04	6.90E+09	6.27E+09	6.27E+07	2.27E-05	1.10E+06	1.15E+06	1.91E+08
N-16	7.38E-01	3.69E-03	7.09E+03	0.00E+00	0.00E+00	6.71E-04	5.52E+01	5.52E+00	7.22E+06
Na-24	2.08E+00	1.04E-02	3.64E+09	0.00E+00	0.00E+00	1.89E-03	2.72E+07	2.83E+06	2.04E+07
Sr-89	4.03E-02	2.02E-04	5.35E+09	0.00E+00	0.00E+00	1.46E-04	6.98E+06	6.28E+06	3.94E+05
Sr-90	2.70E-03	1.35E-05	9.48E+08	0.00E+00	0.00E+00	1.00E-05	4.87E+05	5.27E+05	2.64E+04
Sr-91	5.33E-02	2.67E-04	6.01E+07	0.00E+00	0.00E+00	1.93E-04	1.85E+06	1.87E+05	5.21E+05
Y-91m	1.47E-02	7.36E-05	1.43E+06	0.00E+00	0.00E+00	5.28E-05	4.39E+04	4.39E+03	1.44E+05
Y-91	5.95E-03	2.98E-05	8.64E+08	0.00E+00	0.00E+00	2.13E-05	1.02E+06	9.35E+05	5.82E+04
Y-93	1.28E-03	6.41E-06	1.52E+06	0.00E+00	0.00E+00	4.50E-06	4.54E+04	4.58E+03	1.25E+04
Nb-95	6.41E-03	3.20E-05	6.11E+08	0.00E+00	0.00E+00	2.29E-05	1.08E+06	8.98E+05	6.27E+04

Replace these columns with "B"

Table 12.2-18 (3 of 3)

Isotope	SG Water (Bq/g)	SG Steam (Bq/g)	Blowdown Mixed Bed (Bq)	Blowdown Pre-Filter (Bq)	Blowdown Post-Filter (Bq)	Condensate (Bq/g)	CPS Cation Bed (Bq)	CPS Mixed Bed (Bq)	Flash Tank (Bq)
Mo-99	3.42E+00	1.71E-02	2.68E+10	0.00E+00	0.00E+00	1.23E-02	4.25E+08	8.24E+07	3.35E+07
Tc-99m	1.70E+00	8.48E-03	1.18E+09	0.00E+00	0.00E+00	6.30E-03	3.75E+07	3.75E+06	1.66E+07
Ru-103	2.15E-03	1.08E-05	2.28E+08	0.00E+00	0.00E+00	7.91E-06	3.75E+05	3.19E+05	2.10E+04
Ru-106	9.16E-04	4.58E-06	2.74E+08	0.00E+00	0.00E+00	3.38E-06	1.64E+05	1.73E+05	8.96E+03
Ag-110m	6.38E-02	3.19E-04	1.77E+10	0.00E+00	0.00E+00	5.80E-05	2.81E+06	2.93E+06	6.24E+05
Te-129m	7.32E-02	3.66E-04	6.78E+09	0.00E+00	0.00E+00	2.66E-04	1.26E+07	1.03E+07	7.16E+05
Te-129	3.91E-02	1.96E-04	5.24E+06	0.00E+00	0.00E+00	1.43E-04	1.63E+05	1.63E+04	3.83E+05
Te-131m	3.35E-01	1.68E-03	1.17E+09	0.00E+00	0.00E+00	1.20E-03	2.89E+07	3.60E+06	3.28E+06
Te-131	3.69E-02	1.85E-04	1.79E+06	0.00E+00	0.00E+00	1.34E-04	5.59E+04	5.59E+03	3.61E+05
Te-132	2.39E+00	1.20E-02	2.18E+10	0.00E+00	0.00E+00	8.62E-03	3.12E+08	6.71E+07	2.34E+07
Ba-137m	~~1.65E-01~~ 5.52E+00	~~8.25E-04~~ 2.76E-02	~~8.17E+05~~ 1.94E+12	0.00E+00	0.00E+00	6.29E-04	2.66E+04	2.66E+03	~~1.61E+06~~ 5.40E+07
Ba-140	5.02E-02	2.51E-04	1.79E+09	0.00E+00	0.00E+00	1.78E-04	8.02E+06	4.48E+06	4.91E+05
La-140	1.65E-02	8.25E-05	7.74E+07	0.00E+00	0.00E+00	6.08E-05	1.71E+06	2.44E+05	1.61E+05
Ce-141	1.88E-03	9.40E-06	1.70E+08	0.00E+00	0.00E+00	6.66E-06	3.14E+05	2.56E+05	1.84E+04
Ce-143	4.87E-03	2.44E-05	1.87E+07	0.00E+00	0.00E+00	1.82E-05	4.62E+05	5.98E+04	4.77E+04
Ce-144	5.50E-03	2.75E-05	1.57E+09	0.00E+00	0.00E+00	1.91E-05	9.28E+05	9.71E+05	5.38E+04
W-187	1.15E-01	5.73E-04	3.19E+08	0.00E+00	0.00E+00	1.04E-04	2.16E+06	2.48E+05	1.12E+06
Np-239	1.05E-01	5.23E-04	6.86E+08	0.00E+00	0.00E+00	9.51E-05	3.10E+06	5.34E+05	1.02E+06

Replace these columns with "C"

Isotope	Condensate (Bq/g)	CPS Cation Bed (Bq)	CPS Mixed Bed (Bq)
Kr-85m	0.00E+00	0.00E+00	0.00E+00
Kr-85	0.00E+00	0.00E+00	0.00E+00
Kr-87	0.00E+00	0.00E+00	0.00E+00
Kr-88	0.00E+00	0.00E+00	0.00E+00
Xe-131m	0.00E+00	0.00E+00	0.00E+00
Xe-133m	0.00E+00	0.00E+00	0.00E+00
Xe-133	0.00E+00	0.00E+00	0.00E+00
Xe-135m	0.00E+00	0.00E+00	0.00E+00
Xe-135	0.00E+00	0.00E+00	0.00E+00
Xe-137	0.00E+00	0.00E+00	0.00E+00
Xe-138	0.00E+00	0.00E+00	0.00E+00
Br-84	2.43E-04	0.00E+00	1.28E+05
I-131	9.50E-02	0.00E+00	1.71E+10
I-132	1.73E-02	0.00E+00	3.97E+07
I-133	1.29E-01	0.00E+00	2.70E+09
I-134	6.87E-03	0.00E+00	5.94E+06
I-135	6.61E-02	0.00E+00	4.44E+08
Rb-88	1.36E-02	4.00E+06	4.00E+05

"A"

Isotope	Condensate (Bq/g)	CPS Cation Bed (Bq)	CPS Mixed Bed (Bq)
Cs-134	1.08E-02	5.27E+08	5.63E+08
Cs-136	1.48E-03	6.65E+07	3.75E+07
Cs-137	1.25E-02	6.10E+08	6.61E+08
Cr-51	1.54E-03	7.23E+07	5.60E+07
Mn-54	7.14E-05	3.46E+06	3.63E+06
Fe-55	5.35E-05	2.60E+06	2.79E+06
Fe-59	1.34E-05	6.37E+05	5.57E+05
Co-58	2.05E-04	9.82E+06	9.28E+06
Co-60	2.36E-05	1.15E+06	1.24E+06
Zr-95	1.73E-05	8.30E+05	7.75E+05
Zn-65	2.27E-05	1.10E+06	1.15E+06
N-16	6.71E-04	5.52E+01	5.52E+00
Na-24	1.89E-03	2.72E+07	2.83E+06
Sr-89	3.67E-05	1.75E+06	1.58E+06
Sr-90	2.45E-06	1.19E+05	1.29E+05
Sr-91	4.85E-05	4.65E+05	4.68E+04
Y-91m	1.34E-05	1.11E+04	1.11E+03
Y-91	5.41E-06	2.59E+05	2.38E+05
Y-93	1.16E-06	1.18E+04	1.19E+03
Nb-95	5.82E-06	2.75E+05	2.28E+05

"B"

Isotope	Condensate (Bq/g)	CPS Cation Bed (Bq)	CPS Mixed Bed (Bq)
Mo-99	3.11E-03	1.08E+08	2.09E+07
Tc-99m	1.54E-03	9.18E+06	9.18E+05
Ru-103	1.96E-06	9.28E+04	7.91E+04
Ru-106	8.33E-07	4.04E+04	4.26E+04
Ag-110m	5.80E-05	2.81E+06	2.93E+06
Te-129m	6.66E-05	3.14E+06	2.58E+06
Te-129	3.56E-05	4.08E+04	4.08E+03
Te-131m	3.05E-04	7.33E+06	9.12E+05
Te-131	3.35E-05	1.40E+04	1.40E+03
Te-132	2.18E-03	7.87E+07	1.69E+07
Ba-137m	1.25E-02	6.10E+08	6.61E+08
Ba-140	4.57E-05	2.05E+06	1.15E+06
La-140	1.50E-05	4.23E+05	6.03E+04
Ce-141	1.71E-06	8.07E+04	6.57E+04
Ce-143	4.43E-06	1.13E+05	1.46E+04
Ce-144	5.00E-06	2.42E+05	2.54E+05
W-187	1.04E-04	2.16E+06	2.48E+05
Np-239	9.51E-05	3.10E+06	5.34E+05

"C"

Daughter nuclide impact on the SWMS

TS

Table 1 Daughter nuclide build up in SRLTST

TS

TS

TS

TS

Shielding for pipe lines

TS

TS

Table 3 Shielding analysis results (shielding thickness) for valve room 085-P03

TS

RAI 343-8420 - Question 12.02-23_Rev.2

RAI 343-8420 - Question 12.02-23_Rev.3

Table 12.2-11 (2 of 2)

Nuclide	Purification	Deborating	Pre-Holdup	Boric Acid Condensate
Te-129m	1.3E+12	4.1E+09	2.6E+09	1.9E+05
Te-129	1.9E+09	1.7E+07	2.2E+06	~~8.1E-01~~ 1.2E+05(2)
I-131	1.2E+14	9.6E+11	2.2E+11	9.3E+06
Te-131m	2.1E+11	1.9E+09	2.9E+08	2.5E+03
Te-131	1.2E+09	1.1E+07	1.4E+06	~~1.9E-01~~ 5.6E+02(2)
Te-132	4.0E+12	3.6E+10	6.3E+09	1.3E+05
I-132	4.0E+11	3.6E+09	4.6E+08	~~3.5E+02~~ 1.3E+05(2)
I-133	1.9E+13	1.7E+11	2.5E+10	1.6E+05
I-134	9.2E+10	8.4E+08	1.1E+08	3.1E+01
Cs-134	3.5E+14	2.0E+09	6.1E+12	1.6E+04
I-135	3.5E+12	3.2E+10	4.2E+09	9.2E+03
Cs-136	2.3E+12	2.7E+08	3.9E+10	1.3E+03
Cs-137	5.0E+14	2.3E+09	8.6E+12	1.9E+04
Ba-140	3.2E+11	9.2E+05	6.6E+08	2.4E+02
La-140	1.4E+10	3.1E+05	2.3E+07	1.4E+01
Ce-141	3.1E+10	3.4E+04	6.7E+07	1.3E+01
Ce-143	3.5E+09	9.2E+04	5.4E+06	3.4E+00
Ce-144	5.4E+11	1.0E+05	1.2E+09	4.9E+01
Na-24	7.0E+11	4.1E+07	1.0E+09	6.7E+02
Cr-51	9.4E+12	7.2E+10	2.1E+10	4.5E+03
Mn-54	8.0E+12	1.1E+10	1.9E+10	7.0E+02
Fe-55	8.3E+12	8.0E+09	1.9E+10	5.3E+02
Fe-59	3.3E+11	1.7E+09	7.4E+08	1.1E+02
Co-58	8.0E+12	2.8E+10	1.8E+10	1.8E+03
Co-60	4.0E+12	3.6E+09	9.2E+09	2.4E+02
Zn-65	2.3E+12	4.5E+05	5.2E+09	2.2E+02
Ba-137m(1)	5.0E+14	2.3E+09	8.6E+12	1.9E+04
W-187	6.0E+10	2.2E+06	8.9E+07	5.8E+01
Np-239	1.3E+11	1.9E+06	2.1E+08	1.2E+02

(1) This nuclide is a daughter nuclide in secular equilibrium and the activity is that of the parent nuclide (Cs-137).

(2) The inventories include the contributions from the decay of parents to cover the potential non-conservatism of not including the buildup of daughters due to the decay of Telluriums.

ENCLOSURE 4 to CAW-17-4583

LTR-REA-17-80-NP, Rev. 0, “Response to NRC Comments Regarding RAI 12.02-23,
DAMSAM/SHIELD-APR Daughter Issue”
(Non-Proprietary)

Westinghouse

To:	J.S. Monahan	CWHQ-1 534H	Date:	June 28, 2017
			Direct Tel:	(412) 374-4278
Cc:	L.P. Houssay	CWHQ-3 212	Email:	geerjl@westinghouse.com
	R.B. Sisk	CWHQ-1 520B		
	C.J. Poppe	Windsor, CT	Our ref:	LTR-REA-17-80-NP, Rev. 0

Subject: Response to NRC Comments Regarding RAI 12.02-23, DAMSAM/SHIELD-APR Daughter Issue

References:

1. Westinghouse Letter, LTR-REA-17-8, Revision 0, "Response to RAI 12.02-23, DAMSAM / SHIELD-APR Code Methodology, Daughter Product Issue," February 10, 2017.
2. Combustion Engineering Document, SP-PREC-056, Revision 2, "Verification of SHIELD Computer Code for QA Documentation," 1977.
3. NRC Comments on the responses to RAI 8420, Question 12.02-23, 2017

Following the initial response provided to the NRC regarding RAI 12.02-23 (Reference 1), the NRC issued several comments (Reference 3, attached in EDMS) which this document seeks to address. Primarily this document seeks to address Question 1 parts (a) and (c) which asked for clarification on the Boric Acid Condensate Ion Exchanger (BACIX) and Gas Stripper / Overhead Condenser (GSP / GSOC) respectively. There is also some additional clarification on the question about cycle length (i.e. 480 vs 540 days).

This letter does not document all avenues examined to answer the NRC's questions. It only documents those which provide a basis for the response.

Proprietary and non-proprietary versions of the attachment are included to facilitate submittal to the NRC. Per our procedures the marked redactions are accompanied by one or more of the following designations indicating why the information has been redacted.

a. The information reveals the distinguishing aspects of a process or component, structure, tool, method, etc., and the prevention of its use by competitors of Westinghouse, without license from Westinghouse, gives Westinghouse a competitive economic advantage.

b. The information consists of supporting data (including test data) relative to a process or component, structure, tool, method, etc. and gives Westinghouse a competitive economic advantage, e.g. by optimization or improved marketability.

c. The information, if used by a competitor, would reduce the competitor's expenditure of resources or improve the competitor's advantage in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product.

If you have any questions, please do not hesitate to contact me by telephone (1-412-374-4278) or e-mail (geerjl@westinghouse.com).

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***Electronically approved documents are authenticated in the electronic document management system.**

Attachment B

Non-Proprietary Response

28 June 2017

Contents

Acronyms, Abbreviations, and Terminology

Generic Abbreviations	
DF	Decontamination Factor
CVCS	Chemical Volume Control System
IX	Ion Exchanger[1]
KHNP	Korea Hydro & Nuclear Power
KEPCO	Korea Electric Power Company
APR1400 Components	
PURIX	Purification Ion Exchanger
PURFL	Purification Filter
PHIX	Pre Holdup Ion Exchanger
BACIX	Boric Acid Condensate Ion Exchanger
HUT	Holdup Tank
Gas Stripper Package	
GSP	Gas Stripper Package
GSFP	Gas Stripper, Feed Preheater
GSCOL	Gas Stripper, Stripper Column
GSREB	Gas Stripper, Reboiler
GSOC	Gas Stripper, Overhead Condenser
GSHREX	Gas Stripper, Heat Recovery Exchanger
GSAC	Gas Stripper, Aftercooler

1. Westinghouse codes and calculations tend to use the "Demineralizer (DM)" terminology.

1.0 Clarification of 480 Day Cycle vs 540 Day Cycle

Relevant excerpt from NRC comments:

> “In addition, staff notes that while both DAMSAM and ORIGEN/FIPCO were performed based on a 480 day cycle, the APR1400 DCD indicates that the actual operating cycle is assumed to be 18 months (which would be longer than 480 days). Therefore, some of the conservatism added by accounting for five cycles is taken away by the shortened cycle length and the extra two cycles doesn’t appear to have more than a small impact on the source strength anyway.”

The APR1400 cycle length of 18 month (540 days) includes not only the power operation period, but also the shutdown period. The expected Effective Full Power Days (EFPD) for the APR1400 is 480 days in an 18 month cycle.

The timing details used for the DAMSAM cycles are reproduced in Table 1-1 below.

Table 1-1 Shutdown data from DAMSAM output (all five cycles are identical)

Event	Day
Shutdown	480
Fuel Pull	490
Startup	547

The total cycle length used by DAMSAM is 547 days of which it is at full power for 480 days, this is equivalent to having an 88% capacity factor.

At the end of the five cycles DAMSAM has simulated 2400 EFPD. Operating for three 18-month cycles even at a 100% capacity factor would result in a core operating for only 1643 EFPD. Long lived nuclides’ activities (e.g. ^{137}Cs, ^{85}Kr) tend to be proportional to total burnup; while short lived nuclides will re-reach equilibrium within the burn step of the final cycle.

The use of EFPD to characterize reactors is well established in the industry. For example, in Chapter 12 of Westinghouse’s AP1000 DCD the basis is three 18-month-cycles with a 95% capacity factor; for a total of 1561 EFPD.

Using the EFPD to characterize a core maximizes any nuclides that are proportional to power.

2.0 Overhead Condenser / Gas Stripper Package

2.1 Introduction

The gas stripper package is treated with a single shielding model and its source is the sum of its constituent parts. As such the source term for the gas stripper package and overhead condenser will be discussed as one component.

In SHIELD-APR the gas stripper is divided into six parts:

- Feed Preheater
- Stripper Column
- Reboiler
- Overhead Condenser
- Heat Recovery Exchanger
- Aftercooler

All parts—except the Overhead Condenser—are treated as simple volumes: i.e. their source terms are just their volumes multiplied by the activity concentration of their influent. Because of this, only the overhead condenser is susceptible to the daughter issue. The simple volumes are unaffected by the daughter issue as they do not consider any decay, and as such do not lose the daughter nuclides without considering generation.

2.2 Refined Error Estimate

The upper bound estimate on the error due to neglecting daughters that was presented in the original response was derived to be conservative for every component; in the original response it was noted that:

> For components with small residence times relative to the half-life of the daughter (Outflow$\gg\lambda j$) this estimate can become much larger than the true error.

The overhead condenser is an example of a component where neglecting the outflow greatly exaggerates the error estimate. The overflow condenser does not reach radiological equilibrium which is what the original upper bound estimate assumes.

The activity in the overhead condenser can be described with a differential balance equation as

[ ]a, b, c

Where

- i is the parent nuclide
- j is the daughter nuclide
- A_x is the activity of the x^{th} nuclide
- a_j is the influent activity concentration of the daughter nuclide
- Q_i is the influent flow rate

- FRAC is an expression for the removal efficiency for each nuclide (based on DF for noble gases and a partition factor for other nuclides)

This equation is a corrected version of the one that is the theoretical basis for the SHIELD code. It neglects outflow from the overhead condenser; instead the activity in the overhead condenser is based on accumulating during a "buildup" time. This is the time it takes for the vapor pressure to increase to the Gas Surge Header pressure, at which point it becomes capable of discharge. This is a short time relative to the half-life of ^{88}Kr which has been identified as the parent of concern.

The following two sections numerically and analytically obtain a refined value for the error estimate.

2.2.1 Numerical Evaluation of Error

Following the example used in the verification of the SHIELD code (Reference 2) with updated parameters:

[ ]$^{a, b, c}$

The buildup time is [ ]^{b,c}, compared to ^{88}Kr's half-life of 2.84 hours. Thus there will not be appreciable daughter generation in the Overhead Condenser. Further, the influent activity concentration to the overhead condenser is taken to be (except for ^{16}N): RCS letdown flowing through the Purification Filter, Purification Ion Exchanger, and Pre-holdup Ion Exchanger, with no decay along the way.

[ ]$^{a, b, c}$

Note that none of these filters or ion exchangers impact the noble gases which are the dominate source in the overhead condenser.

To quantify the effect of this limited build up time; a short script to perform the integration with daughters was written. It calculated the Activity and Photon source using: SHIELD-APR's expression, a time integration routine ignoring daughter build up, a time integration routine accounting for daughter build up. As input it was provided the influent specific activities reported in the original SHIELD-APR runs.

Both the "SHIELD's Expression" and "Ignoring Daughters" calculations are used as verification as they are expected to (and do) match the original SHIELD-APR. Table 2-1 tabulates the results as well as the corresponding photon source. In Table 2-1 ^{88}Rb is bolded as it was the daughter of concern identified in the original response.

Table 2-1 Recalculation of gas stripper photon source term

b, c

There is not a noticeable impact on the photon source strength due to inclusion of daughter build up. Only ^{88}Rb shows any noticeable change; but is several orders of magnitude lower than the total photon source which is dominated by ^{133}Xe.

a, b, c

2.2.2 Analytical Error Evaluation

a, b, c

[ ]

2.3 Modeling Conservatisms

In addition to there being such a small build up time in the Overhead Condenser, the shielding model used for the gas stripper exhibits its own conservatisms.

2.3.1 10% Excess Volume

All parts of the gas stripper have an excess 10% added to their volumes. The relevant code sections (CVCS lines 386 through 392):

[ ]$^{a, b, c}$

All components in the GS—except the overhead condenser—do not account for decay and do not have accumulated nuclides: their activities are calculated as influent specific activity multiplied by their volume (including the +10%). Thus—for components other than the overhead condenser—this translates directly into an extra 10% in source strength. The following table illustrates how much of the gas stripper is made up of these “other components”.

Table 2-2 Gas Stripper Photon Source Strength Summary

[ ]$^{b, c}$

Thus [ ]^{b,c} is directly attributable to the 10% excess volume in the stripper column; which translate to 4.9% of the total gas stripper photon source. This is in excess of the original 3% upper bound on the error due to neglecting the daughters derived in Table 4 of the original response. The original estimate of the error in the gas stripper was [ ]^{b,c}. Therefore the extra 10% volume in a single part of the gas stripper provides more conservatism than the original upper bound on the error.

The increased volume also has the effect of increasing the buildup time in the overhead condenser by 10%. This translates to a higher source term due to approaching closer to equilibrium. The expression used by SHIELD-APR:

[ ]$^{a, b, c}$

In case of the noble gases the saturation, $\left(1 - e^{-\lambda_i t}\right)$, tends to increase 8-9% with a volume increase of 10%. This is shown in Table 2-3.

The biggest contributors to the source term (^{88}Kr, ^{133}Xe, ^{135}Xe) all have ~9% extra activity in the overhead condenser due to the increase in volume.

Table 2-3 Overhead Condenser Saturation With and Without +10% Volume b, c

2.3.2 Shielding Calculation

In the shielding calculation, it was assumed that all sources in the gas stripper are homogeneously mixed in a rectangular box filled with air. Modelling the gas stripper as an air filled box has several conservatisms built in that are difficult to quantify.

In reality much of the gas stripper is normally filled with water which on the scale of the gas stripper ([ ]^{b,c}) can present significant self-shielding.

Additionally the localization effect for the gaseous sources is ignored. Most of the source present in the gas stripper is due to the noble gases which collect in the overhead condenser and have a large component in the stripper column. In the case of the stripper column these gases will collect near the top of the column. By modeling the gas stripper as a homogeneous block the strongest photon sources are brought nearer the dose measurement points.

2.4 Conclusion

Overall for the gas stripper it can be concluded that there was significant over-conservatism in the original error bound estimate from neglecting the pressure build up time. The true error is not numerically discernable given the precision reported by SHIELD-APR.

In addition the gas stripper has nearly 10% extra conservatism due to the increased volume it is modeled with in shielding calculations. There is also additional conservatism from neglecting the liquid component and the self-shielding that it would impart.

For these reasons, the source term and related shielding calculations for the overhead condenser/gas stripper package can be seen to be an appropriate and conservative representation. The identified issue with AHIELD-APR's treatment of daughters does not challenge this conclusion.

3.0 Boric Acid Condensate Ion Exchanger

3.1 Refined Error Estimate

In the original response the estimate for the upper bound on the error was created using an assumption that all daughter nuclides would reach equilibrium with their parents, this does not happen for some nuclides. Table 3-1 contains the result of a refined error estimate.

Table 3-1 Numerical Integration of Balance Equation

b, c

3.2 Decay of Influent during Processing

One assumption that SHIELD-APR makes is that: while processing a batch of fluid from the holdup Tank, no decay occurs in the holdup tank. This assumption can be significantly conservative for short lived isotopes as each batch takes ~3.5 days to process.

Table 3-2 and Table 3-3 tabulate the activity and photon source respective for several parameters:

- Continuous vs. batch operation (See Section 3.3)
- Including vs. excluding daughter generation from parent nuclides
- Accounting vs. neglecting decay in fluid remaining in the Holdup Tank during processing

As Table 3-3 shows, neglecting the decay in the unprocessed fluid has resulted in the photon source calculated by SHIELD-APR being higher than the run where both Daughters and Decay in the HUT are accounted for. For an analytical derivation of the third case (Daughters + Influence Decay) see Section

3.2.1. Appendix A contains the same information as Table 3-2 and Table 3-3 for every possible permutation of the three parameters.

Table 3-2 Maximum Activities in BACIX for several run parameters

b, c

Table 3-3 Maximum Photon Sources for several run parameters

b, c

The result of the above calculations is that while ^{132}I is underreported, there is a significant excess of most other nuclides—predominantly ^{131}I—due to SHIELD-APR neglecting the decay that occurs in the Holdup Tank.

3.2.1 Analytical derivation of maximum activities when accounting for influent decay

a, b, c

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[1] The only 3-Nuclide chain in the BACIX is the ^{131m}Te → ^{131}Te → ^{131}I chain. The effect of decaying ^{131m}Te influent is insignificant on the total ^{131}I activity due to: the half-lives, ^{131m}Te having a greater branching ratio straight to ^{131}I, and ^{131}I being dominated by its concentrations. It is thus ignored for this analysis. The numerical results do include this effect, but it is not noticeable.

a, b, c

b, c

The activities are tabulated using a spreadsheet and reported in Table 3-4. These values coincide with the numerically obtained values reported in Table 3-2 except for a difference of 1 in the least significant decimal place for ^{133}I and ^{134}I. The precision of these results is limited by the precision of the influent values reported by SHIELD-APR.

b, c

Table 3-4 Analytical maximum activities in the BACIX when decay of the influent is accounted for

3.3 Continuous Approximation versus Batch Processing

In SHIELD-APR a simplifying assumption is made for the BACIX's operation. Instead of attempting to model the intermittent batch operation of the BACIX, SHIELD-APR models the component as processing an averaged flow rate for the entire cycle. Figures 3-1 to 3-4 illustrate the difference in operating in batch-mode while accounting for daughters, continuous with daughter generation, and continuous without daughters (SHIELD-APR equivalent).

For these figures "batch" operation was taken to be repeated batches that

- Processed 50,000 gallons at 20 gallons/minute
- Total volume processed over a cycle equal to the amount processed by the continuous cycle
- Downtime between batches was uniformly distributed
- All influent concentrations where those reported by SHIELD-APR

The following figures mark time from the beginning of the first batch being started and end after 480 days.

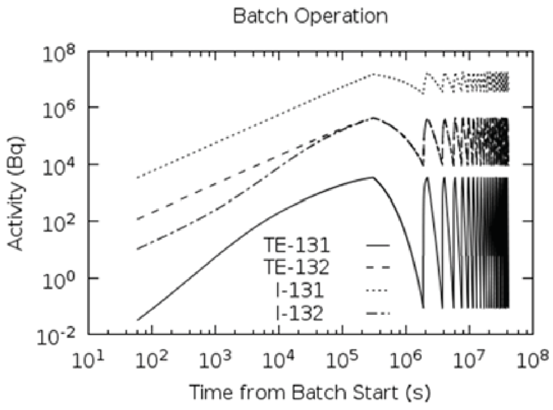

Figure 3-1 Batch Mode, with Daughters

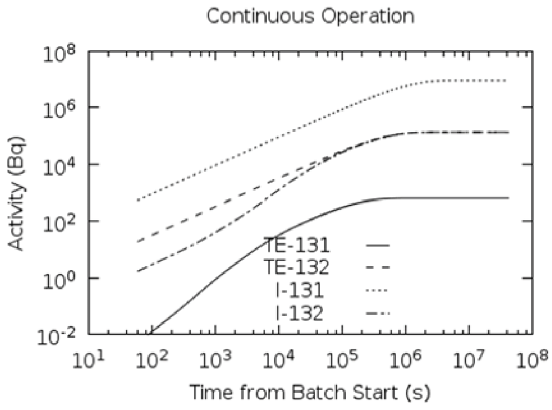

Figure 3-2 Continuous Mode, with Daughters

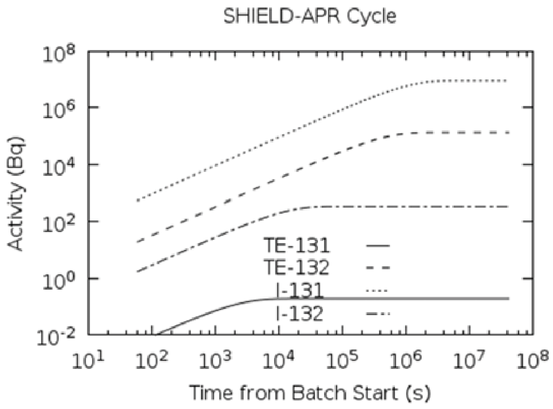

Figure 3-3 Continuous Mode, without Daughters, Equivalent to SHIELD-APR

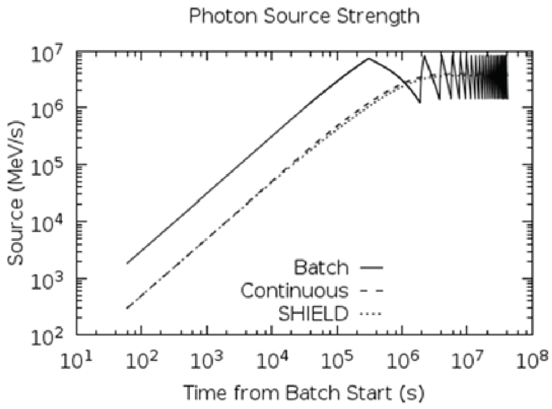

Figure 3-4 Photon Source Strength of the Three Cases

Because the equilibrium value that the activities seek is proportional to flow rate; the realistic 20 gallons/minute flow rate has a much higher source than the lower ~1.6 gallons/minute that represents the averaged “continuous” flow rate. Table 3-5 shows the maximums obtained using a numerical integration script for continuous processing without daughters (equivalent to SHIELD-APR), continuous processing with daughters, and batch processing.

b, c

Table 3-5 Batch and Continuous Mode Comparison

[

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3.4 Administrative Controls for Mitigation

Addressing the increased dose rates due to the buildup of daughter nuclides does not necessarily require increased shielding. The intermittent operation of the BACIX allows for the potential use of administrative controls to mitigate the impact of the daughters. The daughter issue largely affects nuclides with short half-lives (e.g. ^{132}I with 2.3 hours) as those are the ones most sensitive to being neglected, and are also the nuclides which can be allowed to decay away in a reasonable amount of time.

Comparing the continuously operated BACIX, with and without daughter generation (w/o is equivalent to the SHIELD-APR code) it can be seen that it takes [ ]^{b,c} for the photon source to decay to the value reported by SHIELD-APR; due to ^{132}I having such a short half-life. Table 3-6 and Table 3-7 show the activity and photon source respectively for several time periods until the source is equivalent to the one reported by SHIELD-APR.

Table 3-6 Activity in a continuously operated BACIX after a period of decay

b, c

[ ]

Table 3-7 Photon Source in a continuously operated BACIX after a period of decay

b, c

[ ]

From the above tables it would be a reasonable conclusion that administrative controls could be used during the time period immediately following operation of the BACIX in order to prevent unnecessary worker exposure.

If instead batch-mode operation is assumed then the time necessary for the BACIX to cool down to the source calculated by SHIELD-APR is extended to [ ]^{b,c} as shown in Table 3-8 (activity) and Table 3-9 (photon source).

Table 3-8 Activity in a batch operated BACIX after a period of decay

b, c

Table 3-9 Photon Source in a batch operated BACIX after a period of decay

b, c

Appendix A Maximum BACIX activities for different cases

Table A-1 Activity (Bq)

b, c

[ ]

Table A-2 Photon Source Rate (MeV/s)

b, c

[ ]