WESTINGHOUSE ELECTRIC COMPANY

Response to RAI 12.02-23

DAMSAM / SHIELD-APR Code Methodology – Daughter Product Issue

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This document is the non-proprietary version.

Response to RAI 12.02-23

— Outline –

1. Include KHNP response addressing 5 cycles of operation.
2. In addition, there are other inherent conservatisms in:
    - DAMSAM → SHIELD-APR method
        i. DAMSAM always uses maximum activities
        ii. No decay during transit through system
        iii. SHIELD-APR includes the liquid-space activity of the ion exchangers
        iv. SHIELD-APR takes no credit for DBIX removing nuclides from the system
    - The general shielding approach taken on APR1400 (ways of working)
        i. $^{137}Cs \rightarrow {}^{137m}Ba$
        ii. Modeling tanks using low-fraction
3. To evaluate the issue, 4 approaches were taken:
    a. Codes and methodology were carefully reviewed
        i. Determine where daughters show an impact on results
            1. Components which concentrate and then decay parent nuclides
                a. Ion Exchangers
                b. Tanks
                c. Condensers
        ii. Identify sources of conservatism in methodology
        iii. Conclusions from code/methodology review
            1. Most components unaffected
    b. Daughters and components were considered and analyzed
        i. Conclusions for daughters and components
            1. ^{88}Rb in Tanks and Condensers
            2. Te/I in Ion exchangers
    c. Estimate of maximum error was developed
        i. Conclusions from numerical error estimates
            1. ^{88}Rb and ^{132}I dominate
            2. Maximum possible error: per component
    d. Match and comparison performed using Westinghouse code family
        i. Runs performed to develop results:
            1. DAMSAM - SHIELD-APR
                a. Existing work performed by KHNP. DAMSAM is used to find the maximum RCS activities and SHIELD-APR is used to compute the activities in each component
            2. FIPCO - SSP
                a. Westinghouse's codes. ORIGEN to calculate core inventories. FIPCO to calculate RCS, PURIX, and VCT. SSP to calculate RDT.

3. SHIELD-APR /SSP Hybrid
    a. Use the daughters from FIPCO+SSP and the Parents from SHIELD-APR
4. FIPCO → SHIELD-APR
    a. Using FIPCO's results for the RCS that are input into SHIELD-APR, we can eliminate the impact of DAMSAM or ORIGEN on the comparison.

ii. Results and conclusions by component:
1. Letdown Heat Exchanger
    a. Nearly identical results confirm the code analysis
2. Tanks
    a. Volume Control Tank
    b. Reactor Drain Tank
3. Ion Exchangers
    a. Purification Demineralizer (Mixed Bed)
    b. Deborating Demineralizer
        i. Idea for modeling DBIX
        ii. Attempt to confirm validity using influent activities (failed)
        iii. Explanation
        iv. Note SHIELD-APR always runs the DBIX—not crediting for ~20% run time—nor does it credit any downstream components for the DBIX's existence.
4. Discussion – Method – Explanation
    a. Generalization of components
    b. Summary of results
        i. Tanks dominated by noble gases; further conservatism from using low fill fraction for dose calculations.
        ii. Condensers are similar to tanks in that they only concentrate noble gases
            1. ^{133}Xe and ^{135}Xe don't receive significant contribution from their parents compared to other sources.
        iii. Ion Exchangers receive significant conservatism from liquid space—particularly noble gases

iii. Comparison run conclusions

4. Overall conclusions

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Contents

Tables

Abbreviations, Acronyms, and Definitions

- KHNP Korea Hydro & Nuclear Power
- KEPCO Korea Electric Power Company

APR1400 Components

- CVCS Chemical and Volume Control System
- HX Heat Exchanger
  - LDHX Letdown Heat Exchanger
- IX Ion Exchanger, Westinghouse codes refer to these components as Demineralizers.

  - BACIX Boric Acid Condensate Ion Exchanger
  - DBIX Deborating Ion Exchanger
  - PHIX Pre-holdup Ion Exchanger
  - PURIX Purification Ion Exchanger
- Tanks
  - RDT Reactor Drain Tank
  - EDT Equipment Drain Tank
  - VCT Volume Control Tank
  - HUT Holdup Tank
  - IRWST In Containment Reactor Water Storage Tank
  - RMWT Reactor Makeup Water Tank
  - BAST Boric Acid Storage Tank

Scope of WO-74

The scope of WO-74 is limited to evaluation of DAMSAM and SHIELD-APR code conservatisms.

Task 1: Review DAMSAM and SHIELD-APR code analyses for the APR1400 design and identify the conservatisms inherent in the computer models assumptions and input values.

Sections 1 and 2 discuss conservatisms in the code and methodology employed. Section 6 compares the values obtained with values obtained from Westinghouse's code.

Section 5 develops an upper bound on the errors from the generation of daughter nuclides.

Task 2: Review the DAMSAM Code to determine whether the code can be run with the daughter nuclides activities accounted for….

DAMSAM does consider daughter generation; it is SHIELD-APR that does not. There is no way to make SHIELD-APR account for daughter generation without recoding the entire program.

Task 3: Identify an alternate computer code that can calculate the component activities with `explicit` accounting of daughter product.

Section 6 outlines the comparisons performed using Westinghouse's equivalent codes.

Task 4: Review source code for DAMSAM and SHIELD-APR

Section 3 and 4 contain discussions of the code while 5 attempts to quantify an upper bound on the error.

1. Assumption of Five Cycle Operation

In the calculation of RCS source term, most of the fission products reach their equilibrium activity level within one fuel cycle. However, several of the important nuclides (e.g. ^{85}Kr, ^{90}Sr, ^{129}I, and ^{137}Cs) may not reach equilibrium before the fourth or fifth fuel cycle. Therefore to insure maximum reactor coolant activities the code (DAMSAM) is set up to run for four equilibrium fuel cycles with no leakage or load maneuvering waste from the primary coolant. After the simulation for 4 equilibrium cycles, the maximum activity of each nuclide appearing in the RCS during the 5th cycle is taken as the reactor coolant equilibrium concentration. Hence, the duration of reactor operation is provided to 5 in the basis for reactor coolant source term calculations (DCD Table 11.1-1).

For a small number of nuclides this would be non-conservative in a code such as ORIGEN-S which represents variable fission yields. The nuclides affected in this way would be those that demonstrate early peaks due to differing ^{235}U and ^{239}Pu fission yields. The primary nuclides that exhibit this behavior are the bromines and kryptons. However, the only bromine included in ANS 18.1 is ^{84}Br, which does not exhibit the higher ^{239}Pu yield which drives the peaking behavior.

The only isotopes included in the SHIELD-APR which have a higher ^{235}U than ^{239}Pu yield are tabulated in Table 1 below

Table 1 Fission Yields

	Yield	
	U-235	Pu-239
KR-85	5.90E-05	2.40E-05
KR-87	4.60E-03	2.84E-03
KR-88	1.73E-02	7.50E-03
XE-138	4.81E-02	3.93E-02
SR-89	1.80E-04	1.50E-04
MO-99	4.30E-04	3.80E-04
CE-143	3.10E-04	2.70E-04

The last four are not typically considered "peaking" nuclides as the difference in yield is small. The primary concern for the SHIELD-APR analysis will be the Kryptons; of which only ^{87}Kr and ^{88}Kr contribute significantly to the dose. As demonstrated in Section 6 and explained in Section 7.3.3 SHIELD-APR has substantial conservatisms regarding noble gases in tanks due to SHIELD-APR neglecting the decay of gases in the vapor space of tanks.

Additionally any peaking behavior would occur during cycle 1; which will have a lower total source than the calculated equilibrium cycle due to the lack of late equilibrium nuclides.

At any rate, the approach taken by DAMSAM does not specifically model changing fission product yields. Rather, the code makes use of fixed fission product yields calculated by weighting the yields of ^{235}U, ^{238}U, ^{239}Pu, and ^{241}Pu for an equilibrium core. For this reason, there are no nuclides that would demonstrate higher peaks for an earlier cycle, and the approach used would produce the maximum value for all nuclides.

2. Other inherent conservatisms

2.1. DAMSAM → SHIELD-APR method

SHIELD-APR method is conservative in how data is passed to it from DAMSAM. SHIELD-APR is provided nuclide inventories which are independent maximums for each nuclide over the cycle time.

2.2. The general shielding approach taken on APR1400 (ways of working)

The overall approach employed by KHNP has additional conservatisms. When calculating dose rates from tanks a lower fill fraction is used which exaggerates the effect of noble gases on the dose. By considering larger vapor spaces; the effect of shelf shielding from the liquid is reduced.

Additionally in all components the ^{137m}Ba activity is set equal to ^{137}Cs. Because ^{137}Cs only has a 95% branching fraction to ^{137m}Ba, that isn't included, all ^{137m}Ba activities used by KHNP are 5% higher than they would otherwise be.

3. Codes and methodology review

3.1. Determine where daughters generation impacts results

Not all components in SHIELD-APR are impacted by the buildup of daughter products. Many components do not account for any nuclide decay; instead they conservatively use their influent specific activities as their overall specific activity. Components with this treatment are: Heat Exchangers, Pumps, liquid space in Ion Exchangers, liquid space in Filters, Heaters, and Coolers. The only components that do account for decay are: Ion exchangers, Filters, Tanks, and Condensers.

For the components that might be impacted by the generation of daughters; some aren't impacted by all daughters.

Filters and Ion exchangers only account for the decay of the nuclides which they collect—for the filters this only includes crud products. Tanks are the most involved components simulated within SHIELD-APR's code, consisting of a vapor and liquid space in equilibrium. The liquid space in tanks has an extra removal term due to liquid being removed. The Overhead Condenser behaves similarly to Tanks—collecting gases—but does not otherwise account for collection or decay. The Overhead Condenser is also part of the Gas Stripper Package which sums the activities of several components.

3.2. Identify sources of conservatism in methodology

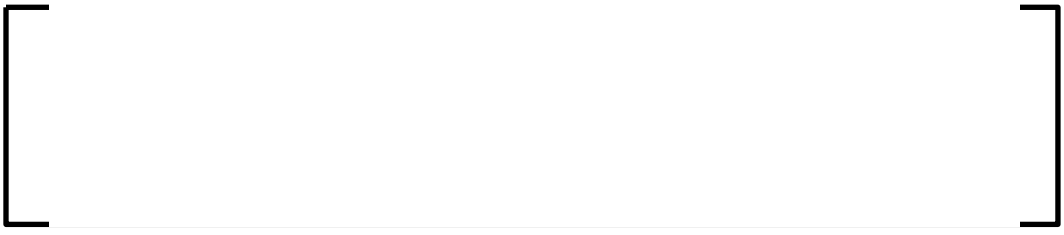
The method employed by DAMSAM is inherently conservative in that DAMSAM independently provides the maximum activity for each nuclide, so that if two nuclides achieve their maximum at different times both are maximized.

SHIELD-APR has several conservatisms in its method. Firstly; it does not account for the decay of nuclides during transmission through the CVCS; it only applies decay once the nuclide is trapped in a component. Some components never account for decay.

Relative to FIPCO / SSP, SHIELD-APR conservatively handles the Ion Exchangers by accounting for the RCS fluid activity flowing through the Ion Exchanger.

SHIELD-APR also does not take credit for nuclide removal by the Deborating Ion Exchanger; all downstream components ignore its contribution. For the DBIX itself, SHIELD-APR assumes it is always operating instead of using an effective DF to account for the intermittent use.

SHIELD-APR (for maximum calculations such as the one performed) considers tanks using the feed and bleed assumption to be at the low fill level for the partitioning of nuclides into their vapor and liquid spaces (to maximize noble gases in the vapor space). SHIELD-APR then adds an undecayed activity to the liquid activity to bring it up to the high fill fraction. For non-noble gases:



a, c

[a, c

]

[

]a,c

For some tanks the difference in fill fraction is significant and results in the majority of the tank's liquid activity not accounting for decay. Table 2 reproduces those fill fractions. All tanks which use this methodology have at least 39% of their liquid volume not accounting for decay. Note: non-bolded tank entries use a different methodology for their calculations

Table 2 CVCS tanks' low and high fractions

[b, c

For noble gases the assumption of low fill is also conservative for the vapor space activity which is the driving concern for shielding. The liquid activity for noble gases is similar to the particulates,

[a, c

But the vapor activity uses Henry's law equilibrium

[a, c

Where H is dependent on the type of noble gas (Kr or Xe). The low fill assumption maximizes the volume quotient.

3.3. Conclusions from code/methodology review

The only components that could be impacted by the daughter issue are: Ion exchangers, Tanks, and the Overhead Condenser. Filters are not impacted due to which nuclides they filter. There are several conservatisms built into SHIELD-APR.

4. Daughters and components analysis

Considering the impact of specific daughters on specific components further reduces the scale of concern

4.1. Daughters

There are a small number of daughter nuclides for the nuclides being tracked:

^{85}Kr	^{95}Nb	^{129}Te	^{135}Cs	^{140}La
^{87}Rb	^{99m}Tc	^{131}I	^{135}Xe	^{143}Pr
^{88}Rb	^{99}Tc	^{131}Te	^{137}Cs	^{144}Nd
^{90}Y	^{106}Rh	^{132}I	^{137m}Ba	^{144m}Pr
^{91}Y	^{110}Ag	^{133}Xe	^{138}Cs	^{239}Pu
^{93}Zr	^{129}I			

Of those only a subset are included in ANSI/ANS 18.1

^{85}Kr	^{95}Nb	**^{131}I**	**^{133}Xe**	**^{137m}Ba**
^{88}Rb	^{99m}Tc	^{131}Te	^{135}Xe	^{140}La
^{91}Y	^{129}Te	^{132}I	**^{137}Cs**	

And of that subset, ^{137m}Ba is handled outside of the SHIELD-APR code. Others (^{85}Kr, ^{131}I, and ^{133}Xe) are dominated by their initial inventories and not their parents' decay.

4.2. Components

SHIELD-APR uses a couple different methods for similar components

4.2.1 Heat Exchangers, Pumps, Heaters, Coolers

These are given very simple treatment in the SHIELD-APR code. The influent specific activity is simply multiplied by the volume. No decay is accounted for.

4.2.2 Ion Exchangers and Filters

Both Ion Exchangers and Filters "trap" specific nuclides and consider the decay for those nuclides. Un-trapped nuclides are treated similarly to heat-exchangers: the influent activity is used without decay. Where these components differentiate is in what nuclides they capture. All filters only capture Crud nuclides—^{51}Cr, ^{54}Mn, ^{55}Fe, ^{59}Fe, ^{58}Co, and ^{60}Co—none of which have radioactive daughters.

The ion exchangers can be divided into two groups based on what they capture, below is a list of elements which are captured and have daughters of concern (excluding ^{137}Cs)

1. Purification and Pre-Holdup
    - Sr, Zr, Mo, Ru, Te, I, and Ba
2. Deborating and Boric Acid Condensate
    - Te and I

Of these, the capture of the Telluriums which decay into the Iodines is the primary concern due to the photons that some of the Iodines emit. Relative to the production of daughter isotopes, the capture of

the Iodines themselves is not a huge concern as they decay into Xenons; which do not remain trapped in the ion exchanger.

For the Deborating Ion Exchanger (DBIX) SHIELD-APR assumes it operates continuously; but doesn't credit any downstream components for the activity it removes. Thus any component downstream of the DBIX has a conservative reported activity; while the DBIX itself also has a conservative activity due to the assumption of continual use.

4.2.3 Tanks

4.2.3.1 Feed and Bleed

Tanks are modeled with a vapor and liquid space. The majority of the noble gases partition off into the vapor space based on Henry's Law. **[**

][a,c] so a different method is used. Particulates and non-equilibrium noble gases use a partition factor to determine the vapor space activity. Due to **[**

][a,c] decay is not accounted for in equilibrium noble gases.

The only time noble gases will have their vapor activity decayed is when the value calculated using the assumption of equilibrium exceeds

[ ] a, c

Where Q_i is the influent flow rate, a_i is the influent activity, and t is the time period (i.e. 100% stripping to the gas phase with no decay for the entire time period).

Of the noble gases:

- ^{85}Kr and ^{133}Xe have stable daughters
- ^{85m}Kr has a relatively small branching ratio to ^{85}Kr (21.4%)
- ^{87}Kr, ^{135}Xe, and ^{138}Xe have daughters not included in ANSI/ANS 18.1.
- ^{131m}Xe,^{133m}Xe, and ^{137}Xe decay to nuclides which have large initial inventories so their contributions are small

That leaves ^{88}Kr as the primary concern.

4.2.3.2 Filling an empty tank

The only tank in the CVCS that uses the methodology that the *SHIELD User Manual* [1] describes for filling empty tanks is the Refueling Shutdown Tank; which isn't used for the APR-1400 design.

4.2.4 Condensers

The Overhead Condensers accumulates nuclides based on either the partition factor (non-noble gases)

[ ] a, c

Or their decontamination factor (noble gases)

[ ] a, c

This is similar to the collection in filters or ion exchangers. For the non-noble gases the partition factor is small; such that they are negligible next to the gases.

The distillate condenser only accumulates noble gases and treats other nuclides in a similar manner to heat exchangers.

4.3. Conclusions for daughters and components

The primary concerns are $^{132}Te/^{132}I$ in the ion exchangers and $^{88}Kr/^{88}Rb$ in the tanks and overhead condenser.

5. Conservative upper bound on error

An attempt was made to quantify an upper bound on the error that ignoring daughter production could have.

Generalized, each component is described by a differential equation,

[ ] a, c

Where Influent is the rate at which new atoms enter the component, and Outflow is the fraction of atoms leaving the component per time unit.

SHIELD-APR is calculating

[ ] a, c

Restating the first equation in terms of the value calculated by SHIELD-APR and an error value

[ ] a, c

This allows us to isolate an expression for the error,

[ ] a, c

This is a fairly simple nonhomogeneous differential equation, the maximum of which can be estimated by setting the derivative equal to zero.

[ ] a, c

In terms of activity this is

[ ] a, c

For conservatism the outflow can be neglected and the estimate of the maximum error becomes just the sum of the parent activities (normally there is only one parent) times their branching fraction. For nuclides in secular equilibrium with their parents (e.g. ^{137m}Ba) this is nearly equivalent to setting their activities equal to their parents. 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.

There are some cases where neglecting outflow is excessively conservative:

- Uncollected nuclides in a filters/ion exchangers
- Components with low residence times (e.g. heat exchangers and pump)

As SHIELD-APR calculates the maximum of A^{shield} and there is no guarantee that the maximum is coincident with the maximum error; this upper bound is possibly even more conservative.

With this upper bound on the error estimate it is possible to go through each component and estimate the total error for that component on a nuclide by nuclide basis for the nuclides that have parents which are decayed in the component.

5.1. Results of error bounds

Some daughter nuclides never have a significant error bounds, such as:

[ ] b, c

The most significant possible errors are for

[ ] b,c

Appendix A has the activities of the daughters for each component from the original SHIELD-APR run. Appendix B has the estimate of the maximum error in the activities; i.e. the activity of the parent nuclides for parents which are collected in that component.

Appendix C is a calculation of the photon source term using SHIELD-APR's energy group structure for the original activities. Appendix D is an estimate of the maximum error in the energy rate.

Appendix E tabulates the contribution of each daughter to the estimated maximum relative error; as well as the total estimate in maximum relative error for the photon source term. Table 3(below) summarizes Appendices C and E for the components with relative error bounds greater than 1%.

Table 3 Components with estimated relative errors greater than 1%

[ ]b, c

5.2. Conclusions from numerical error estimates

Many components have a small estimate of the total photon source error.

Table 4 contains the estimated error fraction in the photon source term for each component using the described methodology. Components whose error exceeds 0.01 are bolded. Only 8 components meet this criterion (the Gas Stripper is a "sum" component of the components in the Gas Stripper Package).

[

]c

Table 4 Total Estimated Photon Source Error (fraction), components with >0.01 error are bolded

b, c

[ ]

6. Comparison with Westinghouse code family

6.1. Runs performed to develop results:

Generation of source terms requires at least two codes

1. KHNP methodology

[a, c]

2. Westinghouse methodology

[a, c]

The equivalence between the two methods isn't exact as the purpose of FIPCO overlaps both DAMSAM and SHIELD-APR; but the bulk of the work SHIELD-APR performs is analogous to parts of FIPCO. To examine the conservatism of SHIELD-APR several run scenarios are considered.

6.1.1 DAMSAM/SHIELD-APR

The primary results to be compared are from the process that KHNP performed using DAMSAM and SHIELD-APR. These are the results included in the SAR.

6.1.2 FIPCO/SSP

The first result compared to the existing work is a comparison using the equivalent Westinghouse codes.

ORIGEN is used to generate the fission products in the core. In the KHNP method DAMSAM performs this task among others.

FIPCO is a code to describe the buildup of fission products in defective fuel elements, the primary coolant system, and the major components of the reactor coolant and purification systems. [ ]a,c. It performs a task roughly equivalent to DAMSAM and parts of SHIELD-APR.

SSP is a code to calculate the gamma ray energy spectra source terms for components. These sources can subsequently be input to MICROSHIELD to perform dose analyses.

[ ]a,c

6.1.3 SHIELD-APR/SSP Hybrid

The first attempt to quantify the impact of the daughter issue on SHIELD-APR while limiting the influence of DAMSAM and ORIGEN based inputs was to create a hybrid nuclide activity profile. The activities computed by SHIELD-APR were supplemented by replacing the Daughter activities with the FIPCO / SSP activities (only if SSP was higher). This combined activity profile was used to examine the effect on the dose rate.

6.1.4 FIPCO/SHIELD-APR

To remove the impact of the different RCS values a fourth run was performed. For this run the RCS values computed by FIPCO were used as the input for SHIELD-APR. And the results compared to the FIPCO/SSP run. Doing this eliminated any conservatism from DAMSAM.

6.1.5 Input Parameters

6.1.5.1 FIPCO

FIPCO is used to obtain most of the results for the Westinghouse Methodology. Code parameters were selected based on the advice in the *FIPCO User Manual* [2] and existing FIPCO input decks demonstrating parameters known to provide good numerical results.

Table 5 FIPCO plant parameters

[ ]a, c

[ ]a, c

Each run case further defines:

Table 6 FIPCO case specific parameters

[ ]a, c

6.1.5.2 SSP

Most values reported in this response come straight from FIPCO. The only values which do not are the RDT values taken from SSP's [

]^{a,c}

Table 7 SSP Parameters

[a, c

]

6.2. Activity and energy group calculations

[a, c

]

Not all components are comparable due to differences between the APR-1400 and the Westinghouse plants that Westinghouse codes model. Only some major components can be directly compared:

1. Letdown Heat Exchanger
2. Purification Ion Exchanger (called the mix bed demineralizer in FIPCO)
3. Volume Control Tank
4. Reactor Drain Tank

An additional component, the Deborating Ion Exchanger, was partially modeled. For this component, however, dissimilarities between the plant designs and their corresponding computer codes kept the comparison from being as direct as for the four listed above. This is further described in the section on the Deborating Ion Exchanger.

For the source calculation, the energy group structure from SSP was used (Table 8) as well as the source strength per energy bin used by SSP for each nuclide.

[ ] a, c

b, c

6.2.1 Letdown Heat Exchanger

The letdown heat exchanger is modeled identically in both SHIELD-APR and SSP. No decay is accounted for in either; instead SHIELD-APR takes the activity to be the coolant specific activity times the heat exchanger's volume. SSP reports specific activities so it just repeats the input reactor coolant specific activity. The inclusion of this result is to demonstrate that SHIELD-APR follows convention when dealing with components that don't account for decay.

A photon energy rate (MeV/s) was calculated using the energy bins included in SSP

Table 9 LDHX Energy Group Structure (MeV/s)

[ ] b, c

The major result from this component is that (within significant digits) FIPCO / SHIELD-APR provide the same results as FIPCO / SSP for heat exchangers. This confirms that SHIELD-APR uses a conventional methodology for components that do not retain nuclides.

b, c

6.2.2 Purification Ion Exchanger

The purification ion exchanger is the first component after the letdown heat exchanger. In FIPCO only the nuclides which are trapped in the resin contribute to the activity; while SHIELD-APR also attributes activity to the reactor coolant flowing through the vessel.

A photon energy rate (MeV/s) was calculated using the energy bins included in SSP

Table 10 PURIX Energy Group Structure (MeV/s) b, c

The first noticeable conservatism in SHIELD-APR is that it accounts for the nuclides in the liquid space of the ion exchanger. Additionally the only daughter that is significantly contributing to the energy rate is ^{137m}Ba—which is the daughter that is handled outside of SHIELD-APR

6.2.3 Volume Control Tank

b, c

The volume control tank is fairly representative of the behavior for tanks: there is a liquid space, and a vapor space.

A photon energy rate (MeV/s) was calculated using the energy bins included in SSP

Table 11 VCT Energy Group Structure (MeV/s) [ ] b, c

The major takeaway from the VCT is that the only nuclides for which FIPCO / SSP have a greater activity than FIPCO / SHIELD-APR are: ^{131m}Xe, ^{133m}Xe, and ^{133}Xe; none of which are significantly greater. At the same time the FIPCO / SHIELD-APR run is much larger for the major daughter nuclides: ^{137}Cs ([ ]^{a,c}), ^{88}Rb ([ ]^{a,c}), ^{132}I ([ ]^{a,c}). The latter two are the daughters which were identified as the major concerns.

The DAMSAM / SHIELD-APR results are also larger than the FIPCO / SSP results for those nuclides, while also being larger for ^{131m}Xe and ^{133}Xe.

6.2.4 Reactor Drain Tank

b, c

A photon energy rate (MeV/s) was calculated using the energy bins included in SSP

Table 12 RDT Energy Group Structure (MeV/s) [ ] b, c

The reactor drain tank is calculated in SSP; but SSP only computes the vapor space activity (only noble gases). For conservatism the specific activity of the liquid space is manually set equal to the reactor coolant's specific activity.

The only noble gases for which FIPCO/SSP is greater than FIPCO/SHIELD-APR are: ^{89}Kr ([ ]^{a,c}) and ^{137}Xe ([ ]^{a,c}). Neither of which are daughters, nor significantly different. The DAMSAM / SHIELD-APR results are similarly larger for all noble gases except: ^{85}Kr ([ ]^{a,c}), ^{133m}Xe ([ ]^{a,c}), and ^{137}Xe ([ ]^{a,c}). Only the ^{85}Kr is a daughter nuclide.

The nuclide of major concern in tanks is ^{88}Rb due to ^{88}Kr build up in the vapor space. For this nuclide FIPCO / SHIELD-APR is [ ]^{a,c} larger than FIPCO / SSP; while DAMSAM / SHIELD-APR is [ ]^{a,c} smaller than FIPCO / SSP; indicating that the difference is mainly due to differences in the initially calculated inventories. The photon energy rate in the tank is governed by the noble gases ([ ]^{a,c}); as such the contribution from ^{88}Rb is reduced. The noble gas daughters dwarf their parents' activity which limits the impact of ignoring daughter generation.

b, c

6.2.5 Deborating Ion Exchanger

An attempt was made to force FIPCO to calculate a value equivalent to the deborating ion exchanger. In SHIELD-APR the influent activity to the deborating ion exchanger is simply the coolant activity minus what gets trapped in the purification ion exchanger, i.e.

[ ] a, c

The attempt involved trying to "trick" the FIPCO code into solving its coolant activity for this post-purification activity so that a modified demineralizer would be equivalent to the deborating ion exchanger calculated by the SHIELD-APR code.

For confirmation the FIPCO coolant activity was compared to the influent activity reported by the FIPCO / SHIELD-APR runs (described in Section 6.1.4). These did not agree everywhere; therefore the results for this component are not directly comparable.

Table 13 Influent to DBIX (Bq/cm^3), bolded nuclides differ by more than 10%

[ ] b, c

[ ] b, c

Nevertheless a photon energy rate (MeV/s) was calculated using the energy bins included in SSP

Table 14 DBIX Energy Group Structure (MeV/s)

[ ] b, c

Few, if any, conclusions can be reliably drawn from this case. This component demonstrates the boundary of applicable comparisons. The one conclusion that can be reliably drawn is that: even though the “Tricked” RCS activity tended to be larger than the FIPCO / SHIELD-APR DBIX influent activity, the FIPCO / SHIELD-APR overall results are higher.

6.3. Dose calculation (Prepared by Dukjin Park, KEPCO E&C (SD))

6.3.1 Calculation of Dose Rates

The purpose of this calculation is to make a survey of the unshielded contact dose rates of selected CVCS components using the various source terms produced by the APR1400 (DAMSAM / SHIELD-APR), WEC (FIPCO / SSP) and FIPCO / SHIELD-APR methodologies, and the combination of DAMSAM / SHIELD-APR and FIPCO / SSP (for daughter nuclides of interest) results. For this survey, MicroShield computer code is used to calculate the dose rates at 1 inch (Point 1) and 1 feet (Point 2) away from the bare (volumetric source only) equipment surface (Figure 2-1). The radioactive source dimensions and parameters of the radiation sources contained in each CVCS component are presented in the APR1400 DCD Table 12.2-25.

MicroShield results are taken for the absorbed dose rates (mGy/hr) of end shielding model in air with buildup. The conversion factors used for photon fluence rate to dose rates are the values from ICRP Publication 51-1987. In general, for source dimension of $y \gg x$, the dose rates for end shielding model are larger than those for side shielding model at the same distance from the sources. But in the both models, the fraction of dose rate due to the different source terms is calculated to be of similar magnitude.

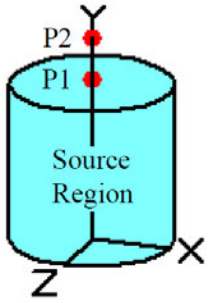


Figure 2-1 End Shielding Model of Cylindrical Sources Contained in CVCS Component

The method of dose rate calculation used in this survey is similar to estimating unshielded contact dose rates used as criteria for radiation zone designation. And the MicroShield is a photon/gamma-ray shielding and dose assessment program which is widely used for shielding analysis.

6.3.2 Comparison of Dose Rates

6.3.2.1 Calculation Methodology for the RCS and CVCS Component Source Terms (DAMSAM / SHIELD-APR vs FIPCO / SSP)

In order to quantify the effect of differences in the calculation methodology for the RCS and CVCS component source terms, the dose rates of selected CVCS components are calculated using the source terms produced by DAMSAM / SHIELD-APR and FIPCO / SSP, respectively. In these two methodologies, SHIELD-APR which is used for the calculation of CVCS component source terms does not take into account the buildup (decay-in) of the daughter nuclides in CVCS components, but SSP contains the accumulation of the daughter nuclides. The APR1400 input parameters used in the calculation of CVCS

component source terms by DAMSAM / SHIELD-APR and FIPCO / SSP are all the same. In this comparison, the fission products listed in the APR1400 DCD (45 nuclides) are only included, but the cruds, H-3 and N-16 are not included for simplicity.

The calculated dose rates of selected CVCS components using the source terms produced by DAMSAM / SHIELD-APR and FIPCO / SSP are tabulated in Table 15. In this table, the calculated dose rates of all selected CVCS components using the source terms by DAMSAM / SHIELD-APR (dose rates in second column) are larger than those calculated using the source terms by FIPCO / SSP. To summarize the causes of these results, the source terms of Ion Exchangers (Demineralizer and DBIX) by FIPCO / SSP do not include noble gases activities, but APR1400 source terms of Purification IX and DBIX include noble gases activities, and the vapor activities of selected tanks by the APR1400 methodology (VCT and RDT) are much higher than those calculated by FIPCO / SSP. According to these results, it is expected that the buildup of daughter nuclides in the APR1400 source terms do not affect significantly to the original conservativeness.

Table 15 Dose Rates of Selected CVCS Components Using the Source Terms by APR1400 and WEC Methodologies, and FIPCO / SHIELD-APR

[ ] a, b, c

6.3.2.2 Calculation Methodology for the CVCS Component Source Terms (FIPCO / SSP vs FIPCO / SHIELD-APR)

In order to compare the effect of the buildup of daughter nuclides according to the calculation methodology for CVCS component source terms, the dose rates of selected component are calculated

using the two source terms produced by FIPCO / SSP and FIPCO/SHIELD-ARP, respectively. In these FIPCO / SSP and FIPCO / SHIELD-APR methodologies, the same RCS source terms produced by FIPCO are used to calculate the respective CVCS component source terms by SSP and SHIELD-APR. In this comparison too, the fission products listed in the ARP1400 DCD (45 nuclides) are only included. By comparing the dose rates of these two results, it can be directly compared to the results of CVCS component source terms by SHIELD-APR and SSP, and can approximate the effect of the buildup of daughter nuclides.

In Table 15, the SHIELD-APR, for the calculation of CVCS component source terms using the same RCS source terms, yields the more conservative values than SSP (Please refer to the values of fraction of dose rate in the third and fourth columns in Table 15). Although SHIELD-APR does not take into account the buildup of daughter nuclides in the calculation processes, the integrated results of each component is larger than the results by the SPP, which includes the buildup of daughter nuclides from decay of the parent nuclide. In other words, it is considered that the effect of the buildup of daughter nuclides do not have great influence in the calculation of the shield source terms using SHIELD-APR.

6.3.2.3 Addition of Other Fission Products to CVCS Component Source Terms (DAMSAM/SHILD-APR; 45 Nuclides vs FIPCO / SSP and FIPCO / SHIELD-APR; 86 Nuclides)

To evaluate the effect of adding fission products to CVCS component source terms, the dose rates of the selected components are calculated using the extended source terms which include total **[ ]**[a,c] provided by the FIPCO results. The extended source terms are produced for FIPCO / SSP and FIPCO/SHILD-APR cases.

The results of selected CVCS components using the extended source terms are shown in Table 16. In this table, except for the Purification IX, the addition of the remaining nuclides to the source terms not significantly increase the dose rates of CVCS components compared with the results using the 45 nuclides, and the dose rate values are still lower than or similar to the results of the 45 nuclides included in the APR1400 DCD. The results for the Purification IX are mainly due to the larger RCS source terms calculated by FIPCO than by DAMSAM, and neither by the buildup of the daughter nuclides in Purification IX nor by the adding of fission products to source terms. Therefore, it is considered that the current APR1400 CVCS component source terms containing 45 fission products are based on very conservative assumptions.

Table 16 Dose Rates of Selected CVCS Components Using the Source Terms Containing 86 Fission Products by FIPCO / SSP and FIPCO / SHIELD-APR

[ ] a, b, c

[ ] b, c

6.3.2.4 Modified APR1400 Source Terms Replaced by the FIPCO / SSP Results

For another comparison of the effect of the buildup of daughter nuclides, the APR1400 shield source terms are modified by replacing the activities produced by FIPCO / SSP for the major daughter nuclides in the CVCS component source terms. The replaced activities of daughter nuclides and the original activities of the substituted nuclides are shown in the Table 17. In this comparison, the modified APR1400 shield source terms include fission products and cruds presented in ARP1400 DCD (45 fission products and 10 cruds), but H-3 and N-16 are not included.

The calculated dose rates of selected CVCS components using the modified APR1400 source terms are shown in Table 18 with the daughter nuclides that have dominant influence on the dose rate changes. The calculated dose rates for all selected CVCS components are smaller than the results using the original APR1400 shield source terms. The activities of the substituent daughter nuclides produced by the FIPCO / SSP increase or decrease relative to the original values in CVCS source terms, so that the overall effects on the dose rate changes act as an decreasing direction. Therefore, the present APR1400 shield source terms are considered to include conservativeness sufficient compensate for the effects of the buildup of the daughter nuclides from decay of parent.

Table 17 Replaced Nuclides and their Activities in the Modified APR1400 Source Terms (1/2)

[ ] a, b, c

[ ] b, c

Table 17 Replaced Nuclides and their Activities in the Modified APR1400 Source Terms (2/2)

[ ] b, c

Table 18 Dose Rates of Selected CVCS Components Using the Modified APR1400 Source Terms Replaced by the FIPCO / SSP Results

[a, b, c]

6.3.3 Conclusion

Comparing the dose rates of selected CVCS components using the source terms in various cases, the APR1400 source terms calculated by DAMSAM / SHIELD-APR for fission products are very conservative and it is estimated that the buildups of daughter nuclides from decay of parent nuclide have little effect on the subsequent shield design.

6.4. Comparison run conclusions

For all components examined comparing the FIPCO / SHIELD-APR and FIPCO / SSP runs demonstrates that SHIELD-APR has inherent conservatisms.

7. Generalization of components

7.1. Letdown Heat Exchanger

The Letdown Heat Exchanger demonstrates that SHIELD-APR does follow some conventions—for some components it is not necessary to model daughter generation as no decay is modeled. This convention of ignoring all decay is used throughout SHIELD-APR; for heat exchangers, liquid space in filters/ion exchangers, pumps, heaters, coolers.

7.2. Ion Exchangers

[a, c

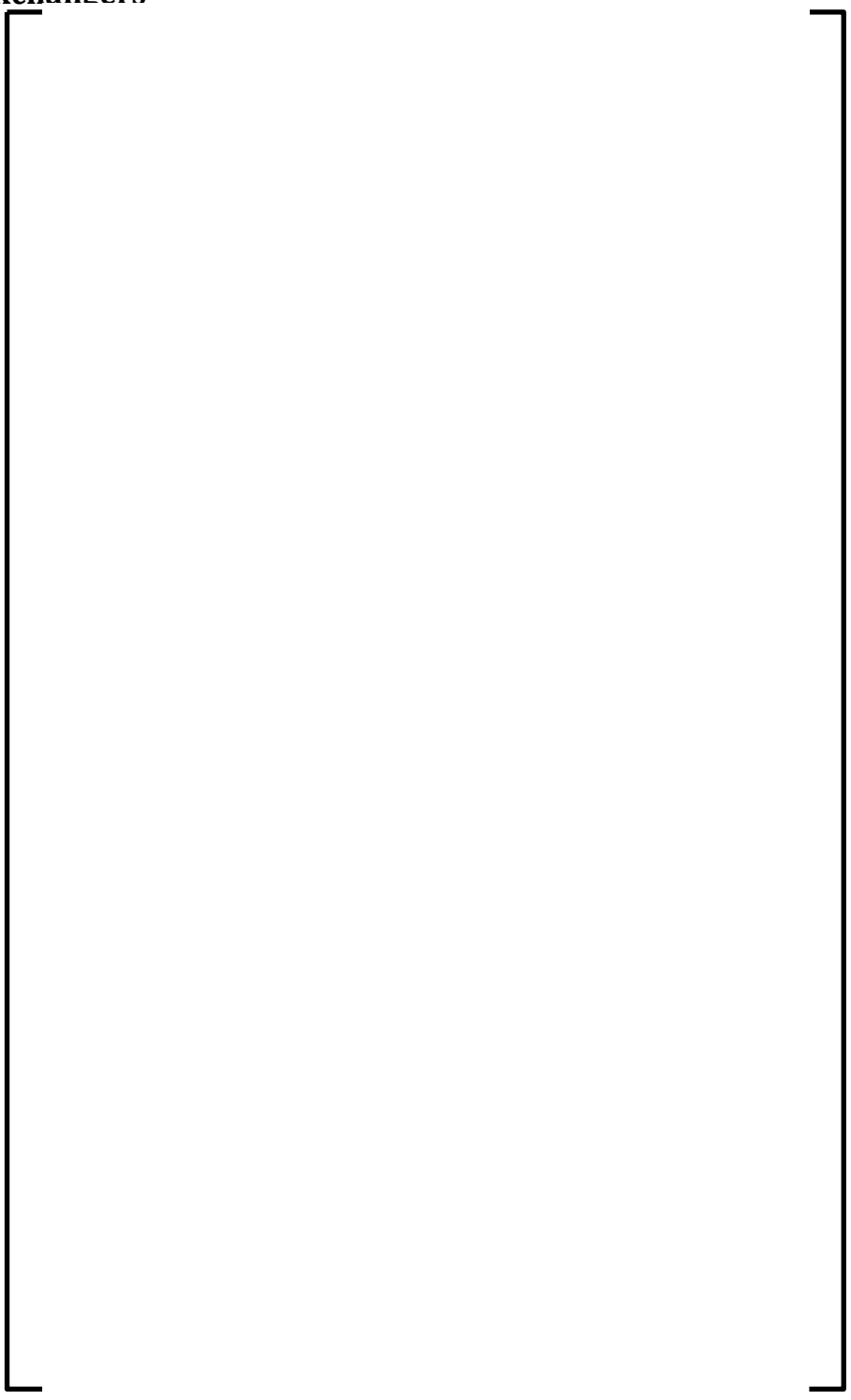


Figure 3 above diagrams the fluid flow that SHIELD-APR models for the components. [

]b,c

The PURIX was compared directly to Westinghouse codes in Section 6.3 and found to demonstrate overall conservatism. The upper bound on its error was calculated at **[ ]**[b,c] but the photon source strength for the FIPCO/SSP run was only **[ ]**[b,c] lower than the DAMSAM/SHIELD results.

Table 19 Sources of PURIX photon source strength conservatism [b, c]

Table 19 above tabulates the major nuclides affecting the photon source strength. Over half the conservatism comes from the excess ^{137m}Ba—including 5% excess activity just from neglecting the 0.95 branching ratio.

The DBIX and BACIX do not receive any conservatism from the excess ^{137}Cs that DAMSAM provides to the RCS—as they do not accumulate Cesium.

The BACIX inherits some conservatism from being downstream of tanks (RDT, EDT, and HUT). The fluid that leaves a tank is taken to have the same nuclide concentration as the tank's liquid component. In the case of the RDT and EDT this activity is calculated using an undecayed volume from the low-fill fraction to the high-fill fraction (See Section 3.2). The EDT has **[ ]**[a,c] of its liquid volume not being credited for any decay; while the RDT has **[ ]**[a,c] of its liquid volume not being credited for decay. But the majority of the flow that ends up going to the BACIX does not pass through the EDT or RDT.

The holdup tank itself is calculated using five components to its liquid space, but only the first two influence the downstream components. The first is the expression for the volume up to the low fill fraction that all tanks use. The second is an expression describing what the activity would be if the holdup tank was filled from the low-fill fraction, up to the high-fill fraction at its maximum inflow rate. It is these two activities combined that make up the effluent concentration.

In both ion exchangers (DBIX and BACIX) the parent-daughter pair that contributes the strongest to the calculated upper bound on the error is the ^{132}Te-^{132}I pair: **[ ]**[b,c] of the estimated error bound for the DBIX and BACIX respectively. ^{132}Te has a half-life of 3.2 days and ^{132}I has a half-life of 2.3 hours; meaning that ^{132}I reaches equilibrium with ^{132}Te relatively quickly.

In the SHIELD-APR input deck, Tellurium is defined as belonging to the anion chemical group—in fact it is the sole member of that group as Bromine and Iodine have a special group. [ ]**[a,c]**

During normal operation Tellurium exists in an insoluble form; it is only once the water has become oxidized (e.g. during refueling) that it becomes solubilized as TeO_4^{2-}. Thus for the majority of the

simulated cycle the amount of soluble Tellurium that is capable of interacting with the ion exchanger resin is reduced. This behavior of Tellurium is captured in SSP for certain demineralizers [

]a,c

7.3. Tanks

DAMSAM / SHIELD-APR demonstrated significant conservatism in the VCT vapor space and extremely large conservatisms in the RDT vapor space for the dose rate. Examining the photon source group structure in the RDT provides some illumination to this result. We can note on a group for group basis the conservatism of the DAMSAM / SHIELD-APR result compared to the FIPCO-SSP result.

Table 20 shows the contribution to the overall conservatism for each energy bin. We can note that only two groups are significantly contributing to this conservatism (bins 3 and 5).

Table 20 RDT Group-wise contribution to conservatism

[ ] b, c

Table 21 identifies the nuclides (that SHIELD-APR models) which contribute to these energy groups.

Table 21 Truncated table of nuclides' energy bin definition (MeV/disintegration). All nuclides with emissions in the 3rd and 5th energy bins

[b, c

The clearest contributor is ^{133}Xe; for which DAMSAM/SHIELD-APR calculated an activity of [ ]^{b} versus FIPCO/SSP's value of [ ]^{b}. We then calculate ^{133}Xe's contribution to the difference in the photon source as [ ]^{b} in Bin 3 and [ ]^{b} in Bin 5 using the activities from Section 6.2.4 (reproduced in Table 22).

In total, ^{133}Xe accounts for [ ]^{b} of the difference in photon source strength (i.e. [ ]^{b}). Table 22 lists several of ^{133}Xe's calculated values for the three main code runs.

Table 22 Xe-133 RDT quantities

[b, c

From the FIPCO/SHIELD-APR result we can observe that [ ]^{b} can be attributed to the effect of DAMSAM on the initial RCS activity (magnified by SHIELD-APR) leaving SHIELD-APR responsible for [ ]^{b}.

There are several factors in SHIELD-APR that are contributing to this conservatism:

7.3.1 SHIELD-APR is executed using the "no gas stripping" option

During the calculation SHIELD-APR does not remove gases from the CVCS; meaning nobles gases (including Xe-133) are built up.

7.3.2 No leakage to other systems is modeled

Similarly SHIELD-APR does not credit the CVCS for any leakage of nuclides

7.3.3 Henry's Law Equilibrium.

SSP treats the RDT activity as being in equilibrium with the RCS and formulates an expression for the RDT vapor activity using Henry's Law Equilibrium as

[ ] a,c

Where:

[ ] a,c

SHIELD-APR calculates it using a series of expression that are equivalent to

[ ] a, c

Where:

[ ] a,c

Rearranging SHIELD-APR's expression to makes it resemble SSP's and assuming equilibrium:

[ ] a, c

We note that there is an extra term in SSP's denominator which accounts for the decay of the nuclide in the vapor space. The α_{RDT}^{Vap} value calculated by SHIELD-APR will always be greater than the corresponding SSP value (if the Henry's Law constants are the same). This is a conservatism in SHIELD-APR. We can quantify the impact of this by dividing through by Q and evaluating the magnitude of the additional denominator term

[ ] a, c

Using the values:

[ ] a,b,c

- $Q = 10.95 \frac{}{s} (250 \text{ gallons per day})$

The terms in the denominator can be calculated for every noble gas (Table 23). For the RDT the vapor term is the dominant term for all cases except ^{85m}Kr.

Table 23 RDT Henry's Law Equilibrium Denominator Values

[ ] b, c

We can even express the conservatism of SHIELD-APR relative to SSP due to this exclusion as

[ ] a, c

All Tanks in SHIELD-APR use the same formulation of Henry's Law, so it is possible to genericize the above equation for any tank.

[ ] a, c

Because the influent has divided out it is possible to evaluate this for every tank using easily obtained quantities. This tabulation for every tank and modeled noble gas is provided in Table 24.

Table 24 Henry Law vapor space conservatisms

b, c

The only place where this becomes negative is in the VCT where the difference in the quantity for Xenon is the dominating feature as the flow rate is high relative to the volume, but this is also one of the tanks directly compared and demonstrated overall conservatism.

These values can be compared to what was observed between the FIPCO/SSP and FIPCO/SHIELD runs. Table 25 below shows differences in each noble gas nuclide for the two runs. For the RDT the conservatism is very close to what was derived above in Table 24. For the VCT some nuclides deviate from the calculated values; but the overall trend is observed and most nuclides have agreement.

Table 25 RDT Vapor Space Activity Comparison

b, c

[

]

One important feature to note from this conservatism is that it is dependent on the fill fraction of the tank. A lower fill fraction (larger vapor volume) means this conservatism becomes larger. Some tanks have very small fill fractions. The relevant parts of Table 2 are reproduced in Table 26 below.

Table 26 Tank low fill fraction

Tank	Low Fraction
Reactor Makeup Water Tank	0.58
Boric Acid Storage Tank	0.40
IRWST	0.76
Holdup Tank	0.05
Volume Control Tank	0.31
Equipment Drain Tank	0.08
Reactor Drain Tank	0.40

[

]b

References

[a, c]

b, c

Appendix A. DAMSAM / SHIELD-APR Daughter Activities (Bq)

b, c

b, c

b, c

b, c

b, c

[

]

b, c

Appendix B. Estimate of maximum error in daughter activities (Bq)

b, c

b, c

b, c

b, c

b, c

b, c

Appendix C. Energy rate (MeV/s) using SSP's 18 energy group structure

b, c

b, c

b, c

b, c

b, c

b, c

Appendix D. Estimate of error in energy rate (MeV/s)

b, c

b, c

b, c

b, c

b, c

b, c

Appendix E. Contribution to estimated error in energy rate (fraction of total photon source)

b, c

b, c

b, c

b, c

b, c

b, c

Appendix F. Reactor Coolant specific activities (Bq/g) for each run

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