FC-18-002
Revision 0
Potential Radionuclides of Concern During the Decommissioning of Fort Calhoun Station

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ACRONYMS AND ABBREVIATIONS

BWR	Boiling water reactor
Ci/g	Curies per gram
MDA	Minimum detectable activity
MWe	Megawatts electric
NRC	United States Nuclear Regulatory Commission
PWR	Pressurized water reactor

1.0 PURPOSE

The purpose of this Technical Basis Document is to document an initial suite of potential radionuclides of concern for the decommissioning of Fort Calhoun Station. Industry guidance is reviewed as are the analysis results associated with representative samples associated with various site activities. The initial suite of potential radionuclides will be used to help define sample analysis requirements associated with decommissioning activities including characterization activities and license termination plan development. It is expected that as additional samples are collected and analyzed, this initial suite of radionuclides will be updated and will eventually represent those long lived radionuclides with a potential to be present at the time of the final status survey.

2.0 DISCUSSION

Fort Calhoun Station (FCS) is located in eastern Nebraska, on the western shore of the Missouri River approximately 20 miles north of Omaha, Nebraska. FCS consists of one pressurized water reactor supplied by Combustion Engineering. The reactor was rated at approximately 500 MWe. The reactor was permanently shut down on October 24, 2016.

As Decommissioning activities commence, numerous samples will be collected requiring radiological analysis. These radiological analyses may support operational health physics concerns; free release surveys, characterizations of equipment, buildings, and the environment; and planning activities associated with the development of a license termination plan. This initial suite of potential radionuclides will help guide the required analyses of these samples. As the decommissioning progresses, additional samples will be collected and analyzed allowing for the initial suite of radionuclides to be updated. Some radionuclides may prove not to have been present, some radionuclides may be removed with the removal of a specific source term, some radionuclides may continue to decay to insignificant activity concentrations, and some radionuclides may be eliminated due to insignificant dose contributions. Eventually an updated suite of radionuclides representative of radionuclides with a potential to be present at the time of final status survey will be prepared. The ultimate goal being to establish a concise list, or lists, of radionuclides present in the various media subject to final status survey.

3.0 INDUSTRY GUIDANCE

To aid in the development of an initial suite of potential radionuclides of concern for the decommissioning of FCS, several industry guidance documents were reviewed to generate a list of potential radionuclides. These guidance documents included NUREG/CR-3474, NUREG/CR-4289 and WINCO-1191. Radionuclide half-lives were obtained from ICRP Publication 38.

NUREG/CR-3474 provides tables of theoretical activation products for both pressurized water reactors (PWR) and boiling water reactors (BWR) based on

typical materials of construction, anticipated impurities, assumed neutron flux, etc. Four tables from NUREG/CR-3474 were reviewed in order to prepare a list of potential radionuclides with half lives of two years or greater. These tables from NUREG/CR-3474 were as follows:

- Table 5.1-Activation of PWR Internals (Ci/gm), Type 305L Stainless Steel, 30 EFPY at Core Axial Midplane
- Table 5.3-Activation of Pressure Vessel Walls (Ci/gm), 30 EFPY at Core Axial Midplane
- Table 5.4-Activation of PWR Bioshield (Ci/gm), Average Concrete, 30 EFPY at Core Axial Midplane
- Table 5.6-Activation of PWR Bioshield (Ci/gm), Average Rebar, 30 EFPY at Core Axial Midplane

Based on a review of the above tables, Table 3-1 was prepared listing the potential radionuclides due to neutron activation of reactor components.

Table 3-1
Potential Activation Products

Radionuclide	Half Life (years)	Radionuclide	Half Life (years)
H-3	1.24E1	Ag-108m	1.27E2
C-14	5.73E3	Sn-121m	5.50E1
Cl-36	3.01E5	I-129	1.57E7
Ar-39	2.69E2	Ba-133	1.07E1
Ca-41	1.40E5	Cs-134	2.06E0
Mn-53	3.70E6	Cs-137	3.00E1
Fe-55	2.70E0	Pm-145	1.77E1
Ni-59	7.50E4	Sm-146	1.03E8
Co-60	5.27E0	Sm-151	9.00E1
Ni-63	9.60E1	Eu-152	1.33E1
Se-79	6.50E4	Eu-154	8.80E0
Kr-81	2.10E5	Eu-155	4.96E0
Kr-85	1.07E1	Tb-158	1.50E2
Sr-90	2.91E1	Ho-166m	1.20E3
Nb-92m	2.70E7	Hf-178m	3.10E1
Zr-93	1.53E6	Pb-205	1.43E7
Mo-93	3.50E3	U-233	1.58E5
Nb-94	2.03E4	Pu-239/240	2.41E4
Tc-99	2.13E5		

NUREG/CR-4289 provides tables of actual sample analysis results obtained from seven nuclear power plants, both PWRs and BWRs, and included both fission and activation products. Four tables from NUREG/CR-4289 were reviewed in order to supplement the list of radionuclides with half lives greater than two years presented in Table 3-1. These tables were as follows:

- Table 4.1-Long-lived Residual Radionuclide Compositions in Total Plant Inventories at Seven Nuclear Generating Stations.
- Table 4.2-Concentration Ranges of Radionuclides in Corrosion Films on Piping Exposed to Primary Reactor Coolant.
- Table 4.3-Concentration Ranges of Radionuclides in Corrosion Films Internally Deposited in Piping and Hardware Exposed to Liquid Radwastes and Secondary Coolant.
- Table 4.4-Concentration Ranges of Radionuclides Associated with Concrete from Highly Contaminated Areas Within Selected Nuclear Generating Stations.

Based on a review of these four tables from NUREG/CR-4289, Table 3-2 was prepared listing potential radionuclides with half lives of two years or greater that were not included in Table 3-1.

Table 3-2
Additional Fission and Activation Products Based on Actual Analysis Results

Radionuclide	Half Life (years)
Pu-238	8.77E1
Np-237	2.14E6
Am-241	4.32E2
Am-243	7.38E3
Cm-244	1.81E1

WINCO-1191, Reference 6.3, presents a theoretical listing of radionuclides expected to be found in both PWRs and BWRs and includes both fission and activation products. Of particular interest is Table 1 entitled "Radionuclides Found in Nuclear Power Reactors (limited to half-lives longer than 50 days)." Table 1 from WINCO-1191 was reviewed in order to supplement the lists of radionuclides with half lives greater than two years presented in Tables 3-1 and 3-2.

Based on a review of Table 1 from WINCO-1191, Table 3-3 was prepared listing potential radionuclides with half lives of two years or greater that were not included in Table 3-1 or Table 3-2.

Table 3-3
Additional Fission and Activation Products Based on Theoretical Considerations

Radionuclide	Half Life (years)
Sb-125	2.77E0
Pm-147	2.62E0
Pu-241	1.44E1

4.0 REPRESENTATIVE SAMPLES

To further aid in the development of an initial suite of potential radionuclides of concern for the decommissioning of FCS the analytical results of representative samples collected at FCS were reviewed. In general the samples associated with these results were collected from within various waste/process streams and sent off site for a 10CFR61-type of analysis. Table 4-1 provides a summary of the samples.

Table 4-1
Summary of Samples Analyzed

Sample Number/Identifier	Date Collected	Media	Description
L70787	10/18/2016	Smear	smear samples from various plant locations.
L71393	1/8/2016	Resin	primary coolant purification media
L71393	2/4/2018	Charcoal	liquid waste processing media
L71393	7/29/2013	Resin	liquid waste processing media
L76112	12/20//2017	Liquid	Spent Fuel Pool
10-Oct-16-200029	10/18/2016	Smear	Room 506 sink
04-Jan-17-200006	1/4/2017	Smear	Room 60 sink
10-Oct-16-200032	10/18/2016	Smear	Spent Fuel Pool
10-Oct-16-200026	10/18/2016	Smear	Room 23 sump
09-Nov-16-200010	11/9/2016	Smear	underside of reactor vessel
04-Nov-16-200011	11/4/2016	filter	upper reactor cavity air sample

Attachment 1 contains a summary of each of the analysis results for the samples. The data summarized in Attachment 1 shows the radionuclides analyzed for, the half-life of each of the radionuclides listed, the activity concentration of each radionuclide detected, the uncertainty in the activity concentration of each radionuclide detected, and the minimum detectable activity (MDA) concentration of each radionuclide analyzed for but not detected. In reviewing which of the radionuclides analyzed for were detected, the MDA of the radionuclides not detected must be considered to ensure that the analytical techniques used were sufficient to detect all the radionuclides of concern.

Attachment 2 contains a summary of the radionuclides in each of the samples that were detected. The radionuclide activity concentrations for each of the radionuclides detected were decay corrected to February 15, 2018. Based on the decay corrected activity concentrations, the relative fraction represented by each radionuclide is provided.

Based on the data contained in Attachment 2, a list of radionuclides with relative fractions equal to, or greater than, 0.001% was generated. Table 4-2 lists those radionuclides that were detected and had a relative fraction equal to, or greater than, 0.001%.

Table 4-2
Radionuclides Relative Fractions Equal To, or Greater Than, 0.001%

Nuclide	µCi Composite Sample	% in Plant	% alpha	% beta	% gamma	Half-life (Years)
Cs-137	2.83E+01	52.8%		52.8%	79.8%	30.04
Ni-63	1.46E+01	27.3%		27.3%		100.10
Co-60	6.90E+00	12.9%		12.9%	19.5%	5.27
Fe-55	3.18E+00	5.9%		5.9%		2.73
Sr-90	2.60E-01	0.49%		0.49%		28.74
Cs-134	2.10E-01	0.39%		0.39%	0.59%	2.06
Pu-241	3.26E-02	0.061%		0.06%		14.35
Mn-54	2.37E-02	0.044%		0.04%	0.07%	0.86
H-3	7.33E-03	0.014%		0.01%		12.33
Ag-110m	6.52E-03	0.012%		0.01%	0.02%	0.68
Am-241	2.89E-03	0.005%	59.2%		0.0082%	432.20
Cm-243/244	9.27E-04	0.002%	18.97%			29.10
Pu-238	8.96E-04	0.002%	18.32%		0.003%	87.70
Pu-239 (1)	1.73E-04	0.0003%	3.53%			24,110

(1) Pu-239 is included due to its significant alpha contribution.

5.0 INITIAL SUITE OF POTENTIAL RADIONUCLIDES

To prepare the initial suite of potential radionuclides of concern for the decommissioning of FCS, NUREG/CR-3474 Tables 4.1, 4.2, 4.3, and 5.13 were used as a basis to form a single list after eliminating noble gases and other short-lived radionuclides since they are not expected to be present at the time of final status survey. Table 5-1 provides the combined list of potential radionuclides.

Table 5-1
Potential Radionuclides

Radionuclide	Half Life (years)	Radionuclide	Half Life (years)
H-3	**12.3**	**Cs-134**	**2.07**
C-14	5,370	**Cs-137**	**30.04**
Cl-36	301,000	Pm-145	17.7
Ca-41	103,000	Pm-147	2.62
Mn-53	3.70E6	Sm-146	1.03E8
Fe-55	**2.73**	Sm-151	90
Ni-59	**76,000**	Eu-152	13.54
Co-60	**5.27**	Eu-154	8.59
Ni-63	**100.1**	Eu-155	4.76
Se-79	650,000	Tb-158	180
Sr-90	**28.74**	Ho-166m	1,200
Nb-92m	3.47E7	Hf-178m	31
Zr-93	1.53E6	Pb-205	1.52E7
Mo-93	4,000	U-233	159,200
Nb-94	20,300	**Pu-238**	**87.7**
Tc-99	211,100	**Pu-239/240**	**24,110**
Ag-108m	418	**Pu-241**	**14.35**
Sn-121m	55	Np-237	2.144E6
Sb-125	**2.76**	**Am-241**	**432.2**
I-129	1.57E7	Am-243	7,370
Ba-133	10.52	**Cm-243/244**	**29.1**

The bolded radionuclides in Table 5-1 represent those radionuclides that were identified in the samples collected from the FCS site.

Upon review of the radionuclides listed in Table 5-1 that were not identified in the samples collected at the FCS site, it became apparent that some of the radionuclides were only included based on the theoretical considerations related to neutron activation. In order to pare down the list of potential radionuclides, the calculated activity concentrations of these theoretical neutron activation products were compared to the calculated activity concentrations of Co-60, Cs-137, and Ni-63. As shown in Attachment 2, the most prominent activation products identified in the samples collected at FCS were Co-60, Cs-137, and Ni-63.

Theoretical neutron activation products listed in Table 5-1 that have calculated activity concentrations less than 0.001% of the calculated activity concentrations of Co-60, Cs-137, and Ni-63 will be eliminated from further consideration. Tables 5.1 and 5.3 of NUREG/CR-3734 provide calculated activity concentrations for PWR Internals and Vessel Walls based on theoretical considerations for neutron activation products. Tables 5.1 and 5.4 of NUREG/CR-6567 contains results from analysis of materials obtained from operating reactors. WINCO-1191 Tables 1 and 2 contains a list of radionuclides found in nuclear reactors that have significant (for decommissioning/disposal purposes) radiological half-lives. Based on the review of this data, the following radionuclides have been eliminated from further consideration; Cl-36, Ca-41, Mn-53, Se-79, Nb-92m, Zr-93, Mo-93, Ag-108m, Sn-12lm, I-129, Ba-133, Pm-145, Sm-146, Sm-151,

Eu-155, Tb-158, Ho-166m, Hf-187m, Pb-205, and U-233. Additionally, Cs-134, Cs-137, Sr-90, Pu-238, Pu-238, Pu-241, and Cm-243/244 were included due to FCS's history with failed fuel elements.

Based on the elimination of the theoretical neutron activation products due to having low activity concentrations relative to either Co-60 or Ni-63, an initial suite of potential radionuclides of concern for the decommissioning of FCS has been prepared. Table 5-2 lists these radionuclides.

Table 5-2
Initial Suite of Potential Radionuclides for the Decommissioning of FCS

Radionuclide	Half Life (years)
H-3	12.3
Fe-55	2.73
Co-60	5.27
Ni-63	100.1
Sr-90	28.74
Cs-134	2.07
Cs-137	30.04
Pu-238	87.7
Pu-239/240	24,110
Pu-241	14.35
Am-241	432.2
Cm-243/244	29.1

As the decommissioning of FCS progresses the list of radionuclides in Table 5-2 may be updated as needed. The collection and analysis of site specific samples should be considered to support specific site activities and or requirements such as the derivation of surrogate relationships between the radionuclides present in support of the final status survey.

6.0 REFERENCES

6.1 NUREG/CR-3474, "Long-Lived Activation Products in Reactor Materials", Pacific Northwest Laboratory, 1984.

6.2 NUREG/CR-4289, "Residual Radionuclide Concentration Within and Around Commercial Nuclear Power Plants; Origin, Distribution, Inventory, and Decommissioning Assessment," Pacific Northwest Laboratory, 1985.

6.3 NUREG/CR-6567, "Low-Level radioactive Waste Classification, Characterization, and Assessment: Waste Streams and Neutron-Activated Metals," Pacific Northwest National Laboratory, 2000.

6.4 WINCO-1191, "Radionuclides in United States Commercial Nuclear Power Reactors," Westinghouse Idaho Nuclear Company, Inc., 1994.

6.5 ICRP Publication 38, "Radionuclide Transformations – Energy and Intensity of Emissions," Pergamon Press, 1983.

7.0 ATTACHMENTS

7.1 Attachment 1 - Sample Analysis Results

7.2 Attachment 2 - Evaluation of Theoretical Neutron Activation Products Relative to Co-60 and Ni-63

Attachment 1
Sample Analysis Results Decay Corrected to 2/15/2018

L70787 - Room 506 sink #1 10/18/2016		
Nuclide	µCi/Sample	% in Plant
Ag-110m		
Am-241		
Cm-243/244		
Co-57		
Co-58	1.87E-05	0.446%
Co-60	4.20E-04	10.018%
Cr-51		
Cs-134		
Cs-137	2.00E-03	47.665%
Fe-55	1.04E-03	24.694%
H-3		
Mn-54	1.25E-05	0.298%
Nb-95		
Ni-63	7.07E-04	16.879%
Pu-238		
Pu-239		
Pu-241		
Sr-90		
Y-90		
Zr-95		

Room 506 sink (10-Oct-16-200029) 10/18/2016		
Nuclide	µCi/Sample	% in Plant
Ag-110m		
Am-241		
Cm-243/244		
Co-57		
Co-58	4.33E-07	0.022%
Co-60	3.49E-04	18.060%
Cr-51		
Cs-134		
Cs-137	1.58E-03	81.918%
Fe-55		
H-3		
Mn-54		
Nb-95		
Ni-63		
Pu-238		
Pu-239		
Pu-241		
Sr-90		
Y-90		
Zr-95		

Room 60 sink (04-Jan-17-200006) 1/4/2017		
Nuclide	µCi/Sample	% in Plant
Ag-110m	1.11E-04	1.053%
Am-241		
Cm-243/244		
Co-57	1.06E-05	0.100%
Co-58	8.27E-05	0.783%
Co-60	9.85E-03	93.265%
Cr-51	2.05E-07	0.002%
Cs-134		
Cs-137	1.32E-04	1.246%
Fe-55		
H-3		
Mn-54	2.18E-04	2.065%
Nb-95	6.75E-06	0.064%
Ni-63		
Pu-238		
Pu-239		
Pu-241		
Sr-90		
Y-90		
Zr-95	1.50E-04	1.421%

L70787 - Room 60 sink #3 10/18/2016		
Nuclide	µCi/Sample	% in Plant
Ag-110m	4.09E-04	0.334%
Am-241	3.22E-05	0.026%
Cm-243/244	3.06E-06	0.003%
Co-57		
Co-58	1.66E-05	0.014%
Co-60	1.13E-01	92.051%
Cr-51		
Cs-134		
Cs-137	6.90E-04	0.564%
Fe-55	2.17E-03	1.775%
H-3		
Mn-54	1.67E-03	1.363%
Nb-95	6.38E-07	0.001%
Ni-63	4.21E-03	3.445%
Pu-238	8.37E-06	0.007%
Pu-239	4.38E-06	0.004%
Pu-241	3.35E-04	0.274%
Sr-90	1.42E-04	0.116%
Y-90	3.18E-59	0.000%
Zr-95	2.90E-05	0.024%

Attachment 1
Sample Analysis Results Decay Corrected to 2/15/2018

L70787 - SFP 10/18/2016		
Nuclide	µCi/Sample	% in Plant
Am-241	1.71E-04	0.032%
Cm-243/244	2.84E-06	0.001%
Co-58		
Co-60	2.48E-02	4.691%
Cs-134	2.95E-03	0.558%
Cs-137	4.93E-01	93.280%
Fe-55	3.13E-03	0.592%
I-129		
Mn-54		
Ni-63	1.81E-03	0.343%
Pu-239	1.05E-05	0.002%
Pu-241	2.56E-03	0.485%
Sr-90	9.01E-05	0.017%
Y-90	2.01E-59	0.000%
Zr-95		

SFP - (10-Oct-16-200032) 10/18/2016		
Nuclide	µCi/Sample	% in Plant
Am-241		
Cm-243/244		
Co-58		
Co-60	4.20E-04	2.171%
Cs-134	1.08E-04	0.559%
Cs-137	1.88E-02	97.270%
Fe-55		
I-129		
Mn-54		
Ni-63		
Pu-239		
Pu-241		
Sr-90		
Y-90		
Zr-95		

L70787 - Rm 23 Sump #2 10/18/2016		
Nuclide	µCi/Sample	% in Plant
Am-241		
Cm-243/244		
Co-58		
Co-60	2.62E-03	17.363%
Cs-134		
Cs-137	1.55E-03	10.272%
Fe-55	7.73E-03	51.226%
I-129		
Mn-54	7.99E-05	0.529%
Ni-63	3.11E-03	20.610%
Pu-239		
Pu-241		
Sr-90		
Y-90		
Zr-95		

Rm 23 sump (18-Oct-16-200026) 10/18/2016		
Nuclide	µCi/Sample	% in Plant
Am-241		
Cm-243/244		
Co-58		
Co-60	1.52E-03	54.238%
Cs-134		
Cs-137	1.17E-03	41.873%
Fe-55		
I-129	1.09E-04	3.889%
Mn-54		
Ni-63		
Pu-239		
Pu-241		
Sr-90		
Y-90		
Zr-95		

Attachment 1
Sample Analysis Results Decay Corrected to 2/15/2018

Upper Rx Cavity A/S (09-Nov-16-200012) 9/16/2016		
Nuclide	µCi/Sample	% in Plant
Ag-110m	5.50E-03	45.789%
Am-241		
Cm-243/244		
Co-57		
Co-58	3.01E-05	0.250%
Co-60	6.19E-03	51.511%
Cr-51	3.00E-08	0.000%
Cs-134		
Cs-137		
Fe-55		
Fe-59	6.58E-08	0.001%
H-3		
Mn-54	2.10E-04	1.751%
Nb-95	1.16E-06	0.010%
Ni-59		
Ni-63		
Pu-238		
Pu-239		
Pu-241		
Sb-125		
Sr-90		
Zn-65		
Zr-95	8.27E-05	0.689%

Upper Rx Cavity A/S (04-Nov-16-200011) 11/4/2016		
Nuclide	µCi/Sample	% in Plant
Ag-110m	1.20E-05	0.375%
Am-241		
Cm-243/244		
Co-57	3.27E-06	0.102%
Co-58	2.93E-05	0.913%
Co-60	3.02E-03	94.282%
Cr-51	6.33E-09	0.000%
Cs-134		
Cs-137	1.81E-05	0.565%
Fe-55		
Fe-59	9.11E-08	0.003%
H-3		
Mn-54	7.34E-05	2.289%
Nb-95	7.53E-07	0.023%
Ni-59		
Ni-63		
Pu-238		
Pu-239		
Pu-241		
Sb-125		
Sr-90		
Zn-65	1.16E-05	0.362%
Zr-95	3.48E-05	1.086%

Primary Resin (L71393) 1/8/2018		
Nuclide	µCi/Sample	% in Plant
Ag-110m		
Am-241	7.16E-04	0.001%
Cm-243/244	9.41E-04	0.002%
Co-57		
Co-58		
Co-60	7.85E+00	13.977%
Cr-51		
Cs-134	3.11E-01	0.554%
Cs-137	2.85E+01	50.790%
Fe-55	4.31E+00	7.680%
Fe-59		
H-3		
Mn-54	5.71E-02	0.102%
Nb-95		
Ni-59	2.12E-01	0.377%
Ni-63	1.46E+01	25.971%
Pu-238	8.68E-04	0.002%
Pu-239	1.50E-04	0.000%
Pu-241	3.00E-02	0.053%
Sb-125		
Sr-90	2.67E-01	0.476%
Zn-65		
Zr-95		

Process Charcoal (L71393) 2/4/2018		
Nuclide	µCi/Sample	% in Plant
Ag-110m		
Am-241	1.25E-05	0.005%
Cm-243/244	8.09E-06	0.003%
Co-57	3.42E-04	0.125%
Co-58	1.98E-02	7.203%
Co-60	6.73E-02	24.550%
Cr-51		
Cs-134	3.90E-04	0.142%
Cs-137	2.70E-02	9.838%
Fe-55	4.93E-03	1.798%
Fe-59		
H-3	1.11E-03	0.404%
Mn-54	1.07E-03	0.391%
Nb-95		
Ni-59	1.55E-03	0.565%
Ni-63	1.48E-01	53.951%
Pu-238	2.76E-05	0.010%
Pu-239	7.74E-06	0.003%
Pu-241	1.44E-03	0.524%
Sb-125	1.27E-03	0.463%
Sr-90	6.54E-05	0.024%
Zn-65		
Zr-95		

Attachment 1
Sample Analysis Results Decay Corrected to 2/15/2018

Underside of Rx. Vessel 11/9/2016		
Nuclide	µCi/Sample	% in Plant
Ag-110m	5.59E-04	0.433%
Am-241		
Cm-243/244		
Co-57	7.00E-05	0.054%
Co-58	1.33E-03	1.029%
Co-60	1.24E-01	95.832%
Cr-51	1.32E-06	0.001%
Cs-134		
Cs-137		
Fe-59	2.82E-06	0.002%
H-3		
Mn-54	2.20E-03	1.707%
Nb-94		
Nb-95	1.52E-05	0.012%
Ni-63		
Pu-239		
Pu-241		
Sr-90		
U-233/234		
Zn-65	5.40E-04	0.419%
Zr-95	6.58E-04	0.510%

SFP (L76112) 12/20/2017		
Nuclide	µCi/Sample	% in Plant
Ag-110m		
Am-241		
Cm-243/244		
Co-57		
Co-58	2.31E-06	0.017%
Co-60	5.32E-05	0.400%
Cr-51		
Cs-134	3.11E-05	0.234%
Cs-137	6.05E-03	45.462%
Fe-59		
H-3	6.73E-03	50.592%
Mn-54		
Nb-94		
Nb-95		
Ni-63	3.89E-04	2.921%
Pu-239		
Pu-241		
Sr-90	4.97E-05	0.374%
U-233/234		
Zn-65		
Zr-95		

Attachment 2
Evaluation of Theoretical Neutron Activation Products Relative to Co-60 and Ni-63

	From Table 5.1 of NUREG CR-3734				From Table 5.3 of NUREG CR-3734
	Shroud	**Core Barrel**	**Thermal Pads**	**Vessel Cladding**	**Pres Vessel Walls**
Radionuclides	**Activity (Ci/g)**	**Activity (Ci/g)**	**Activity (Ci/g)**	**Activity (Ci/g)**	**Activity (Ci/g)**
Co-60	1.3E-01	1.4E-02	2.0E-03	3.3E-04	3.2E-02
Ni-63	1.8E-02	2.4E-03	3.8E-04	5.4E-05	5.7E-03
0.01% Limit	1.8E-06	2.4E-07	3.8E-08	5.4E-09	5.7E-07
Cl-36	5.1E-07	6.4E-08	1.0E-08	1.4E-09	1.6E-07
Ca-41	4.7E-09	5.6E-10	8.6E-11	1.2E-11	1.4E-09
Mn-53	3.3E-09	2.1E-10	1.0E-11	6.9E-12	4.6E-10
Se-79	6.1E-10	4.6E-11	4.7E-12	1.2E-12	1.0E-10
Nb-92m	1.2E-12	6.5E-14	3.2E-15	2.0E-15	4.5E-14
Zr-93	1.1E-10	3.9E-12	2.9E-13	8.6E-14	1.0E-11
Mo-93	9.4E-07	3.9E-08	2.1E-09	1.1E-09	7.7E-08
Ag-108m	<1E-7	<9E-9	<1.1E-9	<2.2E-10	<2.0E-8
Sn-121m	4.8E-09	3.4E-10	1.7E-11	1.1E-11	<7.6E-18
I-129	<6E-13	<1.4E-14	<7.9E-16	<1.1E-16	<4.2E-14
Ba-133	<6E-6	<3E-7	<4.5E-8	<7.1E-9	<7.4E-7
Pm-145	8.9E-10	1.4E-10	2.2E-11	3.1E-12	<3.1E-10
Sm-146	1.0E-16	1.3E-17	6.7E-19	4.3E-19	2.9E-17
Sm-151	4.6E-09	4.5E-09	2.9E-09	5.9E-10	3.8E-9
Eu-152	0.00	9.1E-10	**1.7E-07**	**7.6E-08**	2.2E-14
Eu-154	5.7E-07	**6.0E-07**	**6.2E-08**	**1.2E-08**	**9.1E-07**
Eu-155	4.1E-07	1.4E-07	5.0E-09	5.2E-10	3.6E-07
Tb-158	1.9E-09	1.7E10	8.5E-12	5.6E-12	3.8E-10
Ho-116m	1.6E-07	1.3E-08	1.1E-09	3.0E-10	2.8E-08
Hf-178m	4.3E-08	2.8E-08	3.1E-09	1.2E-09	<3.7E-8
Pb-205	1.8E-12	1.3E-13	1.3E-14	3.4E-15	2.9E-13
U-233	<3.6E-10	1.0E-10	1.1E-11	3.4E-12	<1.6E-10

Bolded/shaded values exceed 0.01% of either the Co-60 or Ni-63 activity concentrations.