ZION UNITS 1 AND 2

ACTIVATION ANALYSIS

AND COMPONENT CHARACTERIZATION

Report 07-046D-RE-088

January 2008

WMG Project
07-046D

Prepared for:

EnergySolutions

Prepared by:

16 Bank Street
Peekskill, NY 10566

FOREWORD

This report summarizes the activation analysis work performed by WMG, Inc. to support EnergySolutions' decommissioning of Zion Station Units 1 and 2. This work was performed by WMG, Inc. under EnergySolutions' Purchase Order No. PO-001531.

Proprietary Notice

TABLE OF CONTENTS

1.0 INTRODUCTION 1

2.0 NEUTRON TRANSPORT AND ACTIVATION METHODOLGY 2

2.1 ANISN DISCRETE ORDINATES NEUTRON TRANSPORT CALCULATIONS 2
2.2 ORIGEN 2.1 NEUTRON ACTIVATION CALCULATIONS 2

3.0 ESTIMATED COMPONENT RADIOACTIVITY AND CLASSIFICATION STATUS 5

3.1 OVERVIEW 5
3.2 COMPONENT RADIOACTIVITY 8

3.2.1 Upper Internals Assembly 8
3.2.1.1 Upper Core Plate 9
3.2.1.2 Balance of Upper Internals 10
3.2.2 Core Barrel Assembly 11
3.2.3 Thermal Shield 12
3.2.4 Core Baffle Assembly 13
3.2.5 Lower Internals 14
3.2.5.1 Lower Core Plate 15
3.2.5.2 Balance of Lower Internals 16
3.2.6 Reactor Vessel Assembly 17
3.2.6.1 Reactor Vessel Wall 18
3.2.6.2 Stainless Steel Vessel Cladding 19

4.0 NORMALIZATION 20

5.0 REFERENCES 21

LIST OF TABLES

Table	Title	Page
2-1	Zion Unit 1 Operating History	4
2-2	Zion Unit 2 Operating History	4
3-1	Zion Unit 1 Component Activation Activity and Part 61 Status Table	6
3-2	Zion Unit 2 Component Activation Activity and Part 61 Status Table	7
3-3	Zion Unit 1 and 2 Upper Core Plate Characterization Results	9
3-4	Zion Unit 1 and 2 Upper Internals Characterization Results	10
3-5	Zion Unit 1 and 2 Lower Core Barrel Characterization Results	11
3-6	Zion Unit 1 and 2 Thermal Shield Characterization Results	12
3-7	Zion Unit 1 and 2 Baffle Plates Characterization Results	13
3-8	Zion Unit 1 and 2 Baffle Formers Characterization Results	14
3-9	Zion Unit 1 and 2 Lower Core Plate Characterization Results	15
3-10	Zion Unit 1 and 2 Balance of Lower Internals Characterization Results	16
3-11	Zion Unit 1 and 2 Reactor Vessel Wall Characterization Results	18
3-12	Zion Unit 1 and 2 Reactor Vessel Cladding Characterization Results	19

LIST OF FIGURES

Figure	Title	Page
2-1	Zion Units 1 and 2 ANISN Radial Thermal Flux Distribution	3
2-2	Zion Units 1 and 2 ANISN Axial Thermal Flux Distribution	3

1.0 INTRODUCTION

In August 2007, EnergySolutions engaged WMG to support Project Greenfield at the former Zion Nuclear Power Station (Zion). Phase 1 of the contract awarded to WMG included the characterization and classification of the Zion Units 1 and 2 reactor vessel(s) and internals using demonstrated and approved methodologies. This report summarizes the results of WMG's analytical methodology used to complete this phase of work and presents the results in terms of activation product content within the reactor pressure vessel and internals. The results presented herein are based on analytical data as well as empirical data. The empirical data exists in the form of surveillance capsule analysis data (References 1-4).

The preliminary results presented in this report will require further normalization after representative surveys have been obtained from each unit in accordance with the survey plan provided in November 2007 (Reference 5). The reported results are considered preliminary because normalization to measured dose rates has yet to occur and because surface contamination, which covers the surfaces of the reactor vessel and internals, has yet to be evaluated.

Based on WMG's extensive experience, surface contaminants do not dictate the NRC waste classification of the activated components. However, the surface contaminant activity, which adds relatively small quantities of activation products, fission products and transuranics, has to be considered prior to packaging the Low Level Radioactive Waste (LLRW) for disposal.

The reactor vessels and internals components are dimensionally the same between Zion Units 1 and 2. However, each unit has a unique operating history, and unique reactor vessel material resulting in different activation results. With the exceptions of drawing-specific material specifications, material data from Reference 6 was used. Low-cobalt stainless steel was specified for components closest to the active core including the baffle plates, formers, and upper and lower core plates.

The relevant activation product radionuclide concentrations determined from these results were used to classify the reactor pressure vessel and internals according to the requirements of 10 CFR Part 61. The activation product scaling factors are also presented in this report and will be used to quantify the hard to detect radionuclide concentrations important to final classification under 10 CFR Part 61. The reported scaling factors are Co-60 based and are final.

The neutron transport and activation analysis methods used for this project are discussed in Section 2. The component specific results in terms of estimated activation activity and 10 CFR Part 61 status as of March 1, 2008 are presented in Section 3. Normalization and benchmarking of the results are discussed in Section 4. References are presented in Section 5.

2.0 NEUTRON TRANSPORT AND ACTIVATION METHODOLOGY

The ANISN (Reference 7) computer program is used to estimate neutron fluxes at various radial and axial locations in the vessel using the BUGLE-96 (Reference 8) cross-section library. The resultant fluxes are normalized to surveillance capsule analysis results. These normalized fluxes are used as inputs to the ORIGEN2.1 (Reference 9) computer program to perform activation analysis on individual components. This section discusses the models developed for the project and summarizes program output.

The same ANISN/ORIGEN methodology has been used to support decommissioning activities at 15 reactors including San Onofre 1, Shoreham, Yankee Rowe, Trojan, Saxton, Maine Yankee, Connecticut Yankee, Millstone 1, and Rancho Seco. The methodology has been refined and benchmarked over the years and has been found to provide reasonable characterization results for the components of interest.

Although the operational history differs between the Zion Units, the neutron flux results are comparable between the units because of the virtually identical dimensions, materials and temperatures of the reactor vessel and internals assemblies. The different operating histories primarily affect the activation calculations due to relative changes in power and irradiation periods.

2.1 ANISN Discrete Ordinates Neutron Transport Calculations

The ANISN code is used to develop one-dimensional radial and axial neutron transport models. The ANISN cylindrical source geometry is used for the radial model, and the slab geometry is used for the axial models. Figures 2-1 and 2-2 summarize the thermal flux distribution for the radial and axial transport calculations respectively normalized to surveillance capsule data.

2.2 ORIGEN 2.1 Neutron Activation Calculations

ORIGEN is used to calculate the activation and depletion of radionuclides in components exposed to a neutron flux. Each component is irradiated based on the plant specific operating histories summarized in Tables 2-1 and 2-2 using the appropriate flux as determined from the ANISN transport models.

FIGURE 2-1
Zion Units 1 and 2 ANISN Radial Thermal Flux Distribution

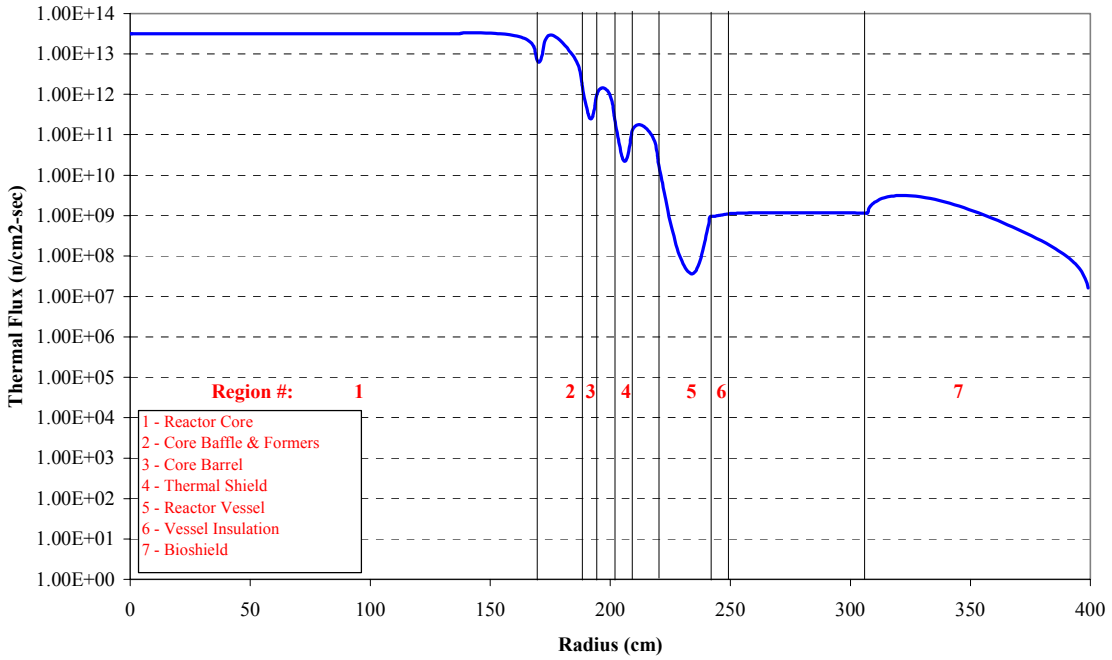

FIGURE 2-2
Zion Units 1 and 2 ANISN Axial Thermal Flux Distribution

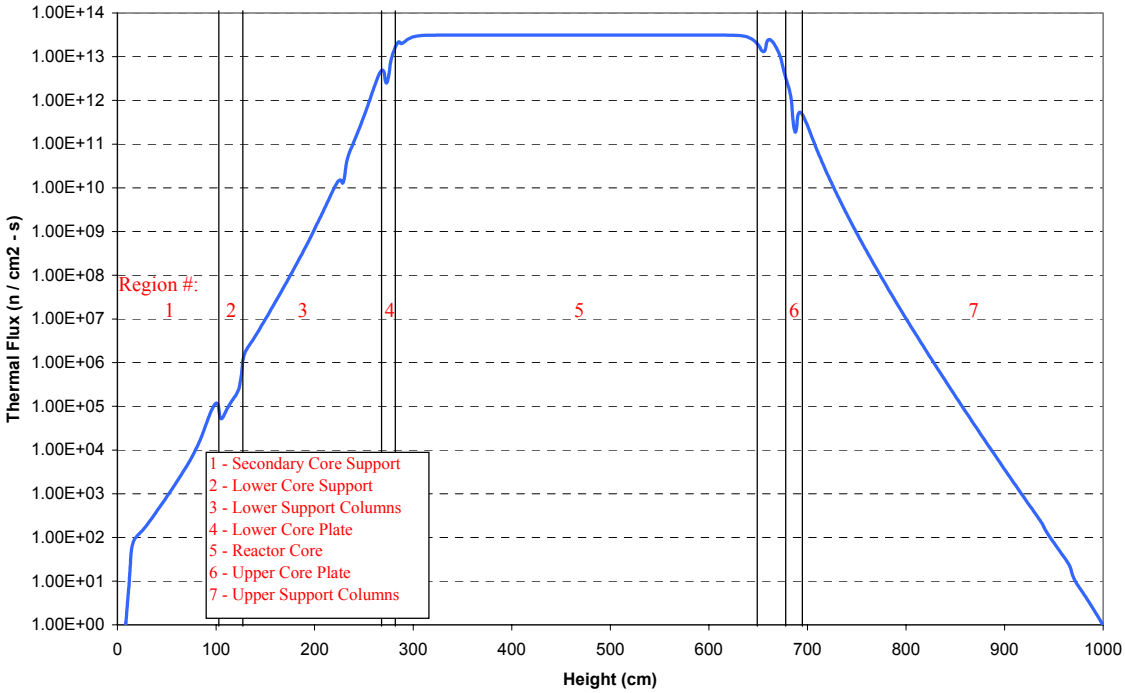

Table 2-1
Zion Unit 1 Operating History

Cycle	Start Date	Stop Date	Length Days	Total Days	EFPDs	Capacity Factors
1	06/19/73	03/05/76	990	1096	444.4	44.89
2	06/19/76	09/09/77	447	533	335.6	75.09
3	12/04/77	09/14/78	284	332	250.0	88.03
4	11/01/78	10/06/79	339	475	274.3	80.92
5	02/19/80	01/14/81	330	428	296.3	89.79
6	04/22/81	02/13/82	297	441	283.6	95.48
7	07/07/82	09/07/83	427	585	324.1	75.90
8	02/12/84	01/30/85	353	490	253.5	71.81
9	06/16/85	09/04/86	445	642	381.9	85.83
10	03/20/87	02/24/88	341	416	291.7	85.53
11	05/09/88	09/07/89	486	627	401.6	82.64
12	01/26/90	02/27/92	762	930	403.9	53.01
13	08/13/92	10/21/93	434	598	392.4	90.41
14	04/03/94	09/09/95	524	623	413.2	78.85
15	12/17/95	02/21/97	432		365.7	84.66

Table 2-2
Zion Unit 2 Operating History

Cycle	Start Date	Stop Date	Length Days	Total Days	EFPDs	Capacity Factors
1	12/24/73	01/07/77	1110	1190	482.4	43.46
2	03/28/77	02/04/78	313	372	281.1	89.82
3	04/04/78	03/09/79	339	379	291.2	85.90
4	04/18/79	05/02/80	380	464	251.1	66.08
5	07/25/80	09/11/81	413	494	342.3	82.89
6	12/01/81	02/24/83	450	542	284.5	63.21
7	05/27/83	03/27/84	305	409	284.8	93.37
8	07/09/84	09/05/85	423	575	378.8	89.56
9	02/04/86	03/25/87	414	550	369.1	89.15
10	08/08/87	10/12/88	431	508	395.8	91.84
11	12/28/88	03/01/90	428	610	361.8	84.53
12	08/30/90	11/12/92	805	907	476.1	59.15
13	02/22/93	01/06/95	683	786	459.5	67.28
14	04/19/95	09/19/96	519		462.8	89.18

3.0 ESTIMATED COMPONENT RADIOACTIVITY AND CLASSIFICATION STATUS

This section presents the estimated activity for each component of interest as of March 1, 2008. These preliminary estimates are based on activation analysis results and, as stated previously in this report, will require normalization to measured dose rates to be considered final. The activities presented in this section represent the activation products only.

3.1 Overview

The activation results of all components presented in this section are based on ORIGEN output using ANISN generated flux levels normalized to surveillance capsule data. Normalization to measured dose rates will change the activation activity for each component but will not change the component-specific scaling factors. Based on WMG's past experience, normalization to measured dose rates is expected to reduce component total activity and possibly NRC waste classification for some of the components.

Tables 3-1 and 3-2 summarize the preliminary results in terms of total activation activity, Co-60 activity, and 10 CFR Part 61 classification status. The estimated activity for all components, which includes the reactor vessel and internals is approximately 930,000 curies per unit as of March 1, 2008. Curie contents discussed in the text are per unit approximations representative of both units. The reactor vessel insulation was not included in the activation portion of the analysis due to lack of any pertinent physical information. The Greater Than Class C (GTCC) components contain approximately 850,000 curies, or about 90% of the total activity. The components are separated into two basic categories in Tables 3-1 and 3-2 below. These categories are GTCC components and LLRW components.

The GTCC components will have to be segmented and either stored on site or selectively concentration averaged with other components for classification as LLRW. The GTCC components are the core baffle plates, the baffle formers and the lower core plate. The remainder of the components meets all 10 CFR Part 61 requirements for disposal as LLRW. The LLRW components include Class A, B & C waste. The Class A LLRW components can be segmented and disposed at an existing commercial disposal site. The Class B & C LLRW must also be segmented, but will be stored on-site because Zion does not currently have access to a disposal facility accepting these wastes.

The GTCC waste consists of nearly 50,000 lbs. of activated metal and contains approximately 850,000 curies per unit. The LLRW internals consist of about 380,000 lbs. of activated metal and contain approximately 80,000 curies. When these LLRW internals are combined with the reactor vessel, there is a total of 548 tons of activated metal containing approximately 81,000 curies as March 1, 2008. The specific characteristics of each significant component in Tables 3-1 and 3-2 are discussed in detail below.

TABLE 3-1
Zion Unit 1 Component Activation Activity and Part 61 Status Table

Component Name	Total Weight (lbs.)	Activity (Ci)	Co-60 Activity (Ci)	10 CFR Part 61 Classification Status
Greater Than Class C Waste				
Baffle Plates and Angles	2.66E+04	5.90E+05	3.37E+05	GTCC
Baffle Formers	1.10E+04	2.17E+05	9.98E+04	GTCC
Lower Core Plate	6.82E+03	3.88E+04	2.20E+04	GTCC
GTCC Subtotals	**4.44E+04**	**8.46E+05**	**4.59E+05**	
Low Level Radioactive Waste				
Lower Internals				
Balance of Lower Internals	7.90E+04	8.78E+03	4.13E+03	A, B & C
Core Region Internals				
Lower Core Barrel	6.17E+04	5.64E+04	3.43E+04	C
Thermal Shield	7.54E+04	9.99E+03	6.11E+03	B
Core Region Internals Subtotal	**1.37E+05**	**6.64E+04**	**4.04E+04**	
Upper Internals				
Upper Core Plate	5.67E+03	3.47E+03	2.04E+03	C
Balance of Upper Internals	1.05E+05	1.17E+03	6.21E+02	A & B
Upper Core Barrel	4.57E+04	5.64E+02	3.43E+02	A
Hold Down Spring	4.15E+03	< 1.0	< 1.0	A
Upper Internals Subtotal	**1.61E+05**	**5.21E+03**	**3.00E+03**	
LLRW Subtotals	**3.77E+05**	**8.04E+04**	**4.75E+04**	
Reactor Pressure Vessel				
Vessel Cladding*	4.73E+03	1.48E+02	8.32E+01	B
Reactor Vessel Wall**	7.14E+05	4.56E+02	1.27E+02	A
RPV Subtotals	**7.18E+05**	**6.03E+02**	**2.10E+02**	
LLRW Internals and RPV Totals	**1.10E+06**	**8.10E+04**	**4.77E+04**	

*vessel clad weight +/- 2 feet active core region only
**total weight - vessel clad, does not include head, studs, nuts & washers

TABLE 3-2
Zion Unit 2 Component Activation Activity and Part 61 Status Table

Component Name	Total Weight (lbs.)	Activity (Ci)	Co-60 Activity (Ci)	10 CFR Part 61 Classification Status
Greater Than Class C Waste				
Baffle Plates and Angles	2.66E+04	5.74E+05	3.30E+05	GTCC
Baffle Formers	1.10E+04	2.11E+05	9.74E+04	GTCC
Lower Core Plate	6.82E+03	3.77E+04	2.15E+04	GTCC
GTCC Subtotals	**4.44E+04**	**8.22E+05**	**4.49E+05**	
Low Level Radioactive Waste				
Lower Internals				
Balance of Lower Internals	7.90E+04	8.53E+03	4.04E+03	A, B & C
Core Region Internals				
Lower Core Barrel	6.17E+04	5.48E+04	3.34E+04	C
Thermal Shield	7.54E+04	9.71E+03	5.95E+03	B
Core Region Internals Subtotal	**1.37E+05**	**6.45E+04**	**3.94E+04**	
Upper Internals				
Upper Core Plate	5.67E+03	3.38E+03	1.99E+03	C
Balance of Upper Internals	1.05E+05	1.14E+03	6.06E+02	A & B
Upper Core Barrel	4.57E+04	5.48E+02	3.34E+02	A
Hold Down Spring	4.15E+03	< 1.0	< 1.0	A
Upper Internals Subtotal	**1.61E+05**	**5.06E+03**	**2.93E+03**	
LLRW Subtotals	**3.77E+05**	**7.81E+04**	**4.42E+04**	
Reactor Pressure Vessel				
Vessel Cladding*	4.73E+03	1.43E+02	8.11E+01	B
Reactor Vessel Wall**	7.14E+05	3.12E+02	7.82E+00	A
RPV Subtotals	**7.18E+05**	**4.55E+02**	**8.88E+01**	
LLRW Internals and RPV Totals	**1.10E+06**	**7.86E+04**	**4.43E+04**	

*vessel clad weight ± 2 feet active core region only
**total weight - vessel clad, does not include head, studs, nuts & washers

3.2 Component Radioactivity

Individual component estimated activation activities are decay corrected to March 1, 2008. NRC Class A and B components include the upper core barrel, hold down spring, thermal shield, reactor pressure vessel, and the balances of the upper and lower internals. These components have relatively low specific activities and may be disposed of intact or segmented and selectively packaged for disposal. The NRC Class C and GTCC components are presented as individual components. These components have relatively high specific activities and must be segmented and packaged either for on-site storage or disposal. Based on the empirical data from previous decommissioning activities, the additional effect of surface contaminants could increase component dose rates marginally but is unlikely to change component classification. As discussed previously, surveys of the internals components are necessary to update the preliminary results presented herein to provide final characterization results.

Activities presented in this report for the components of interest are radionuclides with half-lives greater than 90 days. This is done because of the long cooling time between the end of irradiation and the time of this analysis. As a result, the short-lived activation products (i.e., Co-58, Cr-51, and Fe-59) were considered negligible.

3.2.1 Upper Internals Assembly - Drawing 685J903

The upper internals consist of the upper core plate with fuel assembly guide pins, support columns, Control Element Assembly (CEA) guide tubes, deep beam assembly, and top plate. This region extends upward from the top of the fuel assemblies. The upper internals assembly is removed as a unit during refueling. The upper core plate has a variety of holes for coolant flow and CEA penetration. The upper core plate also has a variety of fuel assembly guide pins attached that interface with the fuel assembly top nozzles for proper alignment. The support columns make the assembly rigid and maintain the distance between the upper core plate and the deep beam/top plate assembly. The CEA guide tubes ensure the CEAs, when withdrawn from the fuel maintain their alignment for insertion. With the exception of the deep beam being welded to the top plate, the other constituents are bolted together. The upper internals assemblies have a total weight of about 111,000 lbs. and contain approximately 4,600 curies.

3.2.1.1 Upper Core Plate – Drawing 685J836

The upper core plate weighs nearly 5,700 lbs. with the fuel assembly alignment pins and contains approximately 3,500 curies. Because of it's close proximity to the active fuel it is the most activated upper internals component. The radionuclide content and distribution, as well as the 10 CFR Part 61 status for the upper core plates is presented in Table 3-3. The upper core plate is NRC Class C waste and will likely require segmentation for packaging and disposal.

TABLE 3-3

Zion U1 Upper Core Plate Characterization Results

Component: U1 Upper Core Plate			
Component Weight (lb.):	5.67E+03		
Total Activity Curies	3.47E+03		
Co-60 Activity Curies	2.04E+03		
Part 61 Table 1 C Fraction	0.42		
Part 61 Table 2 C Fraction	0.37		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	1.29E-06	3.31E+00	1.63E-03
C-14	4.33E-07	1.11E+00	5.47E-04
Mn-54	3.36E-08	8.63E-02	4.24E-05
Fe-55	2.35E-04	6.05E+02	2.97E-01
Co-60	7.92E-04	2.04E+03	1.00E+00
Ni-59	2.50E-06	6.43E+00	3.16E-03
Ni-63	3.20E-04	8.23E+02	4.04E-01
Nb-94	6.98E-09	1.79E-02	8.81E-06
Tc-99	1.61E-09	4.15E-03	2.04E-06
Totals	**1.35E-03**	**3.47E+03**	

Zion U2 Upper Core Plate Characterization Results

Component: U2 Upper Core Plate			
Component Weight (lb.):	5.67E+03		
Total Activity Curies	3.38E+03		
Co-60 Activity Curies	1.99E+03		
Part 61 Table 1 C Fraction	0.42		
Part 61 Table 2 C Fraction	0.37		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	1.27E-06	3.27E+00	1.65E-03
C-14	4.33E-07	1.11E+00	5.61E-04
Mn-54	2.48E-08	6.38E-02	3.21E-05
Fe-55	2.15E-04	5.54E+02	2.79E-01
Co-60	7.73E-04	1.99E+03	1.00E+00
Ni-59	2.50E-06	6.44E+00	3.24E-03
Ni-63	3.21E-04	8.24E+02	4.15E-01
Nb-94	6.99E-09	1.80E-02	9.05E-06
Tc-99	1.61E-09	4.15E-03	2.09E-06
Totals	**1.31E-03**	**3.38E+03**	

3.2.1.2 Balance of Upper Internals

The balance of the upper internals weighs about 105,500 lbs. and contains approximately 1,100 curies. The balance of the upper internals is NRC Class A and B waste, the majority of which can be segmented and packaged for disposal or disposed intact. The radionuclide content and distribution, as well as the 10 CFR Part 61 status, for the balances of the upper internals is presented below in Table 3-4.

TABLE 3-4

Zion Unit 1 Balance of Upper Internals Characterization Results

Component: U1 Balance of Uppers	
Component Weight (lb.):	1.05E+05
Total Activity Curies	1.17E+03
Co-60 Activity Curies	6.21E+02
Part 61 Table 1 A Fraction	0.06
Part 61 Table 2 B Fraction	0.08

Radionuclide	Curies/g	Estimated Curies	Scaling Factors
H-3	2.75E-08	1.31E+00	2.11E-03
C-14	8.52E-09	4.07E-01	6.56E-04
Mn-54	1.87E-10	8.94E-03	1.44E-05
Fe-55	4.86E-06	2.32E+02	3.74E-01
Co-60	1.30E-05	6.21E+02	1.00E+00
Ni-59	5.43E-08	2.59E+00	4.18E-03
Ni-63	6.59E-06	3.15E+02	5.07E-01
Nb-94	7.11E-11	3.40E-03	5.47E-06
Tc-99	9.16E-12	4.38E-04	7.05E-07
Totals	**2.45E-05**	**1.17E+03**	

Zion Unit 2 Balance of Upper Internals Characterization Results

Component: U2 Balance of Uppers	
Component Weight (lb.):	1.05E+05
Total Activity Curies	1.14E+03
Co-60 Activity Curies	6.06E+02
Part 61 Table 1 A Fraction	0.06
Part 61 Table 2 B Fraction	0.08

Radionuclide	Curies/g	Estimated Curies	Scaling Factors
H-3	2.72E-08	1.30E+00	2.14E-03
C-14	8.53E-09	4.08E-01	6.73E-04
Mn-54	1.38E-10	6.61E-03	1.09E-05
Fe-55	4.45E-06	2.13E+02	3.51E-01
Co-60	1.27E-05	6.06E+02	1.00E+00
Ni-59	5.43E-08	2.60E+00	4.28E-03
Ni-63	6.61E-06	3.16E+02	5.21E-01
Nb-94	7.12E-11	3.40E-03	5.62E-06
Tc-99	9.18E-12	4.38E-04	7.23E-07
Totals	**2.38E-05**	**1.14E+03**	

3.2.2 Core Barrel Assembly - Drawing 686J030

The core barrel assembly is a 365-inch long hollow cylinder with an inside diameter of 148 inches and a nominal thickness of nearly 2.3 inches. The core barrel assembly includes the upper and lower core barrels and the core support casting. The hollow cylinder portions of upper and lower core barrel closest to the active core (excluding the core support casting, and the uppermost portion of the upper core barrel) weigh about 61,700 lbs and contain the majority of the approximate 55,000 curies of activity. The component activities, 10 CFR Part 61 status, and scaling factors are summarized in Table 3-5 below. This component is NRC Class C waste and must be segmented and packaged for disposal.

TABLE 3-5

Zion Unit 1 Lower Core Barrel Characterization Results

Component: U1 Lower Core Barrel			
Component Weight (lb.):	6.17E+04		
Total Activity Curies	5.64E+04		
Co-60 Activity Curies	3.43E+04		
Part 61 Table 1 C Fraction	0.68		
Part 61 Table 2 C Fraction	0.52		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	1.88E-06	5.27E+01	1.54E-03
C-14	6.23E-07	1.74E+01	5.09E-04
Mn-54	6.21E-08	1.74E+00	5.07E-05
Fe-55	3.33E-04	9.31E+03	2.72E-01
Co-60	1.23E-03	3.43E+04	1.00E+00
Ni-59	3.48E-06	9.74E+01	2.84E-03
Ni-63	4.54E-04	1.27E+04	3.70E-01
Nb-94	1.20E-08	3.35E-01	9.77E-06
Tc-99	2.97E-09	8.30E-02	2.42E-06
Totals	**2.02E-03**	**5.64E+04**	

Zion Unit 2 Lower Core Barrel Characterization Results

Component: U2 Lower Core Barrel			
Component Weight (lb.):	6.17E+04		
Total Activity Curies	5.48E+04		
Co-60 Activity Curies	3.34E+04		
Part 61 Table 1 C Fraction	0.68		
Part 61 Table 2 C Fraction	0.52		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	1.87E-06	5.23E+01	1.56E-03
C-14	6.24E-07	1.75E+01	5.23E-04
Mn-54	4.60E-08	1.29E+00	3.85E-05
Fe-55	3.05E-04	8.53E+03	2.55E-01
Co-60	1.19E-03	3.34E+04	1.00E+00
Ni-59	3.49E-06	9.76E+01	2.92E-03
Ni-63	4.55E-04	1.27E+04	3.81E-01
Nb-94	1.20E-08	3.35E-01	1.00E-05
Tc-99	2.97E-09	8.31E-02	2.49E-06
Totals	**1.96E-03**	**5.48E+04**	

The uppermost portion of the core barrel assembly (upper core barrel) weighs about 45,700 lbs and based on experience, has an activity of about 1% of the lower core barrel. The upper core barrel contains about 550 curies and is NRC Class A waste. The hold down spring is another low activity NRC Class A waste item.

3.2.3 Thermal Shield - Drawing 684J709

The thermal shield is a 184-inch long hollow cylinder with an inside diameter of 158.5 inches and a nominal thickness of nearly 2.8 inches. The thermal shield weighs about 75,400 lbs. and contains about 10,000 curies. The component activities, 10 CFR Part 61 status, and scaling factors are summarized in Table 3-6 below. This component is NRC Class B waste and must be segmented and packaged for storage and disposal.

TABLE 3-6

Zion Unit 1 Thermal Shield Characterization Results

Component: U1 Thermal Shield			
Component Weight (lb.):	7.54E+04		
Total Activity Curies	9.99E+03		
Co-60 Activity Curies	6.11E+03		
Part 61 Table 1 A Fraction	0.98		
Part 61 Table 2 B Fraction	0.75		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	2.58E-07	8.80E+00	1.44E-03
C-14	8.94E-08	3.05E+00	5.00E-04
Mn-54	9.06E-09	3.10E-01	5.07E-05
Fe-55	4.77E-05	1.63E+03	2.67E-01
Co-60	1.79E-04	6.11E+03	1.00E+00
Ni-59	5.03E-07	1.72E+01	2.81E-03
Ni-63	6.51E-05	2.23E+03	3.65E-01
Nb-94	1.74E-09	5.96E-02	9.76E-06
Tc-99	4.36E-10	1.49E-02	2.44E-06
Totals	**2.92E-04**	**9.99E+03**	

Zion Unit 2 Thermal Shield Characterization Results

Component: U2 Thermal Shield			
Component Weight (lb.):	7.54E+04		
Total Activity Curies	9.71E+03		
Co-60 Activity Curies	5.95E+03		
Part 61 Table 1 A Fraction	0.99		
Part 61 Table 2 B Fraction	0.75		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	2.57E-07	8.78E+00	1.47E-03
C-14	8.95E-08	3.06E+00	5.14E-04
Mn-54	6.70E-09	2.29E-01	3.85E-05
Fe-55	4.37E-05	1.49E+03	2.51E-01
Co-60	1.74E-04	5.95E+03	1.00E+00
Ni-59	5.04E-07	1.72E+01	2.89E-03
Ni-63	6.53E-05	2.23E+03	3.75E-01
Nb-94	1.75E-09	5.97E-02	1.00E-05
Tc-99	4.37E-10	1.49E-02	2.51E-06
Totals	**2.84E-04**	**9.71E+03**	

3.2.4 Core Baffle Assembly - Drawing 686J123

The core baffle assembly is divided into two regions in the radial transport model. These regions are the baffle plate and angles region and the baffle former region. This is done because of the large difference in the water to metal fractions in the two regions. The core baffle is constructed of plates about an inch thick screwed in place to the baffle formers and to each other. The core baffle assembly provides lateral support for the fuel assemblies, directs coolant through the reactor core region, and is the most activated component due to it's proximity to the active fuel. The activation analysis results for these two regions are presented as individual components. The component activities, 10 CFR Part 61 status, and scaling factors for baffles are summarized in Table 3-7 and for the formers in Table 3-8 below. The baffle plates have a total activity in excess of 500,000 curies and weigh about 26,600 lbs. The baffle formers have a total activity more than 200,000 curies and weigh approximately 11,000 lbs. The core baffle assemblies greatly exceed NRC Class C limits and must be segmented and stored on site as GTCC waste.

TABLE 3-7

Zion Unit 1 Baffle Plates Characterization Results

Component: U1 Baffle Plates			
Component Weight (lb.):	2.66E+04		
Total Activity Curies	5.90E+05		
Co-60 Activity Curies	3.37E+05		
Part 61 Table 1 C Fraction	17.3		
Part 61 Table 2 C Fraction	13.4		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	1.88E-05	2.27E+02	6.73E-04
C-14	1.73E-05	2.09E+02	6.19E-04
Mn-54	1.86E-06	2.24E+01	6.66E-05
Fe-55	9.17E-03	1.11E+05	3.28E-01
Co-60	2.80E-02	3.37E+05	1.00E+00
Ni-59	7.31E-05	8.82E+02	2.61E-03
Ni-63	1.17E-02	1.41E+05	4.17E-01
Nb-94	3.16E-07	3.81E+00	1.13E-05
Tc-99	7.02E-08	8.47E-01	2.51E-06
Totals	**4.89E-02**	**5.90E+05**	

Zion Unit 2 Baffle Plates Characterization Results

Component: U2 Baffle Plates			
Component Weight (lb.):	2.66E+04		
Total Activity Curies	5.74E+05		
Co-60 Activity Curies	3.30E+05		
Part 61 Table 1 C Fraction	17.3		
Part 61 Table 2 C Fraction	13.4		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	1.85E-05	2.23E+02	6.77E-04
C-14	1.73E-05	2.09E+02	6.34E-04
Mn-54	1.38E-06	1.66E+01	5.03E-05
Fe-55	8.40E-03	1.01E+05	3.07E-01
Co-60	2.74E-02	3.30E+05	1.00E+00
Ni-59	7.32E-05	8.83E+02	2.68E-03
Ni-63	1.17E-02	1.41E+05	4.27E-01
Nb-94	3.17E-07	3.82E+00	1.16E-05
Tc-99	7.03E-08	8.48E-01	2.57E-06
Totals	**4.75E-02**	**5.74E+05**	

TABLE 3-8

Zion Unit 1 Baffle Formers Characterization Results

Component: U1 Baffle Formers	
Component Weight (lb.):	1.10E+04
Total Activity Curies	2.17E+05
Co-60 Activity Curies	9.98E+04
Part 61 Table 1 C Fraction	11.5
Part 61 Table 2 C Fraction	15.2

Radionuclide	Curies/g	Estimated Curies	Scaling Factors
H-3	2.43E-05	1.21E+02	1.21E-03
C-14	1.87E-05	9.28E+01	9.30E-04
Mn-54	4.37E-07	2.17E+00	2.18E-05
Fe-55	1.03E-02	5.14E+04	5.15E-01
Co-60	2.01E-02	9.98E+04	1.00E+00
Ni-59	9.08E-05	4.51E+02	4.53E-03
Ni-63	1.32E-02	6.56E+04	6.58E-01
Nb-94	1.55E-07	7.73E-01	7.75E-06
Tc-99	2.06E-08	1.02E-01	1.02E-06
Totals	**4.38E-02**	**2.17E+05**	

Zion Unit 2 Baffle Formers Characterization Results

Component: U2 Baffle Formers	
Component Weight (lb.):	1.10E+04
Total Activity Curies	2.11E+05
Co-60 Activity Curies	9.74E+04
Part 61 Table 1 C Fraction	11.5
Part 61 Table 2 C Fraction	15.2

Radionuclide	Curies/g	Estimated Curies	Scaling Factors
H-3	2.38E-05	1.18E+02	1.21E-03
C-14	1.87E-05	9.29E+01	9.54E-04
Mn-54	3.24E-07	1.61E+00	1.65E-05
Fe-55	9.48E-03	4.71E+04	4.83E-01
Co-60	1.96E-02	9.74E+04	1.00E+00
Ni-59	9.10E-05	4.52E+02	4.64E-03
Ni-63	1.32E-02	6.58E+04	6.75E-01
Nb-94	1.56E-07	7.74E-01	7.94E-06
Tc-99	2.06E-08	1.02E-01	1.05E-06
Totals	**4.24E-02**	**2.11E+05**	

3.2.5 Lower Internals

The lower internals include:

Component	Drawings
Core support casting,	685J224
Lower core plate	618F155
Lower support columns	617F593
Support column extensions	649D88, and 5649D86
Flow distributor plate	541F102
Instrument guide tubes	617F596 and 5649D88
Secondary core support	542F115

This region extends from the bottom of the fuel assemblies to the reactor vessel bottom head. The lower internals, including the core support casting, has a total weight of about 86,000 lbs. and contains approximately 47,000 curies. The lower core plate contains approximately 38,000 curies, or about 80% of the total lower internals activity. Understandably this is because the lower core plate is the closest component to the active fuel.

3.2.5.1 Lower Core Plate – Drawing 618F155

The lower core plate, like the upper core plate, is about 2 inches thick, has a variety of through holes and includes bolted-on fuel assembly alignment pins. The lower core plate weighs about 6,800 lbs including the alignment pins, and manway cover, and contains about 38,000 curies. The radionuclide content and distribution, as well as the 10 CFR Part 61 status for the lower core plates is presented in Table 3-9. Because the lower core plates are much closer to the active fuel than the upper core plates, the lower core plates, by themselves, exceed NRC Class C limits and must be segmented and stored on site as GTCC waste.

TABLE 3-9

Zion Unit 1 Lower Core Plate Characterization Results

Component: U1 Lower Core Plate			
Component Weight (lb.):	6.82E+03		
Total Activity Curies	3.88E+04		
Co-60 Activity Curies	2.20E+04		
Part 61 Table 1 C Fraction	3.91		
Part 61 Table 2 C Fraction	3.54		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	1.23E-05	3.81E+01	1.73E-03
C-14	4.20E-06	1.30E+01	5.91E-04
Mn-54	3.10E-07	9.59E-01	4.35E-05
Fe-55	2.28E-03	7.06E+03	3.21E-01
Co-60	7.12E-03	2.20E+04	1.00E+00
Ni-59	2.36E-05	7.30E+01	3.31E-03
Ni-63	3.09E-03	9.55E+03	4.34E-01
Nb-94	6.45E-08	2.00E-01	9.06E-06
Tc-99	1.43E-08	4.43E-02	2.01E-06
Totals	**1.25E-02**	**3.88E+04**	

Zion Unit 2 Lower Core Plate Characterization Results

Component: U2 Lower Core Plate			
Component Weight (lb.):	6.82E+03		
Total Activity Curies	3.77E+04		
Co-60 Activity Curies	2.15E+04		
Part 61 Table 1 C Fraction	3.92		
Part 61 Table 2 C Fraction	3.55		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	1.22E-05	3.76E+01	1.75E-03
C-14	4.21E-06	1.30E+01	6.06E-04
Mn-54	2.29E-07	7.09E-01	3.30E-05
Fe-55	2.09E-03	6.47E+03	3.01E-01
Co-60	6.95E-03	2.15E+04	1.00E+00
Ni-59	2.36E-05	7.31E+01	3.40E-03
Ni-63	3.09E-03	9.57E+03	4.45E-01
Nb-94	6.46E-08	2.00E-01	9.30E-06
Tc-99	1.43E-08	4.43E-02	2.06E-06
Totals	**1.22E-02**	**3.77E+04**	

3.2.5.2 Balance of Lower Internals

The balance of the lower internals weighs about 79,000 lbs. and contains approximately 8,600 curies. The component activities, 10 CFR Part 61 status, and scaling factors for the remaining components are summarized in Table 3-10 below. The balance of the lower internals are NRC Class B waste and must be segmented and packaged for disposal.

TABLE 3-10

Zion Unit 1 Balance of Lower Internals Characterization Results

Component: U1 Balance of Lowers			
Component Weight (lb.):	7.90E+04		
Total Activity Curies	8.78E+03		
Co-60 Activity Curies	4.13E+03		
Part 61 Table 1 A Fraction	0.63		
Part 61 Table 2 B Fraction	0.85		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	2.93E-07	1.05E+01	2.54E-03
C-14	9.72E-08	3.49E+00	8.43E-04
Mn-54	1.89E-09	6.78E-02	1.64E-05
Fe-55	5.43E-05	1.95E+03	4.71E-01
Co-60	1.15E-04	4.13E+03	1.00E+00
Ni-59	5.94E-07	2.13E+01	5.15E-03
Ni-63	7.43E-05	2.66E+03	6.44E-01
Nb-94	7.79E-10	2.79E-02	6.76E-06
Tc-99	9.41E-11	3.37E-03	8.16E-07
Totals	**2.45E-04**	**8.78E+03**	

Zion Unit 2 Balance of Lower Internals Characterization Results

Component: U2 Balance of Lowers			
Component Weight (lb.):	7.90E+04		
Total Activity Curies	8.53E+03		
Co-60 Activity Curies	4.04E+03		
Part 61 Table 1 A Fraction	0.63		
Part 61 Table 2 B Fraction	0.85		
Radionuclide	**Curies/g**	**Estimated Curies**	**Scaling Factors**
H-3	2.89E-07	1.04E+01	2.57E-03
C-14	9.74E-08	3.49E+00	8.65E-04
Mn-54	1.40E-09	5.02E-02	1.24E-05
Fe-55	4.98E-05	1.78E+03	4.42E-01
Co-60	1.13E-04	4.04E+03	1.00E+00
Ni-59	5.95E-07	2.13E+01	5.29E-03
Ni-63	7.44E-05	2.67E+03	6.61E-01
Nb-94	7.81E-10	2.80E-02	6.93E-06
Tc-99	9.43E-11	3.38E-03	8.37E-07
Totals	**2.38E-04**	**8.53E+03**	

3.2.6 Reactor Vessel Assembly

The reactor vessel assembly consists of the reactor vessel, the reactor closure head, the stainless steel vessel cladding closure studs, nuts, and miscellaneous hardware.. The cladding region was separated from the vessel wall region because they are fabricated from two different materials, which are stainless steel and carbon steel, respectively. This causes the activation of these two regions to differ significantly. The curie content for the reactor vessel and cladding regions adjacent to the active fuel is determined using ORIGEN2. Based on previous analytical models and empirical data it is assumed 90 percent of the total activity of the vessel components is located adjacent to the active fuel region. The remaining activity is located $\pm$ 2 feet of the active fuel. The results for the reactor vessel assembly are summarized below.

3.2.6.1 Reactor Vessel Wall

The reactor vessel wall has a total height of approximately 508 inches. The reactor vessel wall has an inner diameter of 173 inches and a wall thickness as thick as 9.5 inches. The reactor vessel wall, including the cladding has a total weight of about 720,000 lbs. and a total activity of approximately 400 curies. Based on experience approximately 99% of the total activity of the reactor vessel wall and clad is contained ± 2 feet of the active core. The results of the characterization and 10 CFR Part 61 status of the reactor vessel walls ± 2 feet of the active core are presented below in Table 3-11. The reactor vessel wall is NRC Class A waste.

TABLE 3-11

Zion Unit 1 Reactor Vessel Wall Characterization Results

Component: U1 Vessel Wall	
Component Weight (lb.):	2.63E+05
Total Activity Curies	4.56E+02
Co-60 Activity Curies	1.27E+02
Part 61 Table 1 A Fraction	0.01
Part 61 Table 2 A Fraction	0.08

Radionuclide	Curies/g	Estimated Curies	Scaling Factors
H-3	2.30E-08	2.75E+00	2.16E-02
C-14	4.70E-10	5.61E-02	4.42E-04
Mn-54	5.36E-10	6.39E-02	5.03E-04
Fe-55	2.60E-06	3.10E+02	2.44E+00
Co-60	1.07E-06	1.27E+02	1.00E+00
Ni-59	9.64E-10	1.15E-01	9.05E-04
Ni-63	1.26E-07	1.51E+01	1.19E-01
Nb-94	1.54E-11	1.84E-03	1.45E-05
Tc-99	3.40E-11	4.06E-03	3.19E-05
Totals	**3.82E-06**	**4.56E+02**	

Zion Unit 2 Reactor Vessel Wall Characterization Results

Component: U2 Vessel Wall	
Component Weight (lb.):	2.63E+05
Total Activity Curies	3.12E+02
Co-60 Activity Curies	7.82E+00
Part 61 Table 1 A Fraction	0.01
Part 61 Table 2 A Fraction	0.06

Radionuclide	Curies/g	Estimated Curies	Scaling Factors
H-3	2.30E-08	2.74E+00	3.51E-01
C-14	4.71E-10	5.62E-02	7.19E-03
Mn-54	3.97E-10	4.73E-02	6.05E-03
Fe-55	2.39E-06	2.85E+02	3.64E+01
Co-60	6.55E-08	7.82E+00	1.00E+00
Ni-59	1.04E-09	1.25E-01	1.60E-02
Ni-63	1.37E-07	1.63E+01	2.09E+00
Nb-94	1.55E-11	1.85E-03	2.36E-04
Tc-99	3.91E-11	4.66E-03	5.96E-04
Totals	**2.61E-06**	**3.12E+02**	

The significant difference between the two reactor vessel walls' scaling factors and Cobalt-60 activities is due to the different material data derived from surveillance capsule reports.

3.2.6.2 Stainless Steel Vessel Cladding

The vessel cladding is a stainless steel weld deposited along the entire inside surface of the reactor vessel and closure head. It has a nominal thickness of $^{5}/_{32}$ inch. The total weight of the cladding ± 2 feet of the active core is about 4,750 lbs. with a total activity of approximately 145 curies. Estimated activities, 10 CFR Part 61 status and scaling factors are summarized below in Table 3-12 for the vessel cladding. The cladding material, an integral part of the reactor vessel, is NRC Class A waste.

TABLE 3-12

Zion Unit 1 Reactor Vessel Cladding Characterization Results

Component: U1 Vessel Clad	
Component Weight (lb.):	4.73E+03
Total Activity Curies	1.48E+02
Co-60 Activity Curies	8.32E+01
Part 61 Table 1 A Fraction	0.17
Part 61 Table 2 A Fraction	0.20

Radionuclide	Curies/g	Estimated Curies	Scaling Factors
H-3	6.92E-08	1.49E-01	1.79E-03
C-14	2.24E-08	4.81E-02	5.78E-04
Mn-54	8.50E-10	1.83E-03	2.19E-05
Fe-55	1.27E-05	2.72E+01	3.27E-01
Co-60	3.87E-05	8.32E+01	1.00E+00
Ni-59	1.40E-07	3.00E-01	3.61E-03
Ni-63	1.71E-05	3.68E+01	4.42E-01
Nb-94	2.36E-10	5.06E-04	6.09E-06
Tc-99	4.10E-11	8.80E-05	1.06E-06
Totals	**6.88E-05**	**1.48E+02**	

Zion Unit 2 Reactor Vessel Cladding Characterization Results

Component: U2 Vessel Clad	
Component Weight (lb.):	4.73E+03
Total Activity Curies	1.43E+02
Co-60 Activity Curies	8.11E+01
Part 61 Table 1 A Fraction	0.17
Part 61 Table 2 A Fraction	0.20

Radionuclide	Curies/g	Estimated Curies	Scaling Factors
H-3	6.91E-08	1.48E-01	1.83E-03
C-14	2.24E-08	4.82E-02	5.94E-04
Mn-54	6.29E-10	1.35E-03	1.66E-05
Fe-55	1.16E-05	2.49E+01	3.07E-01
Co-60	3.78E-05	8.11E+01	1.00E+00
Ni-59	1.40E-07	3.01E-01	3.71E-03
Ni-63	1.72E-05	3.69E+01	4.55E-01
Nb-94	2.36E-10	5.07E-04	6.26E-06
Tc-99	4.10E-11	8.81E-05	1.09E-06
Totals	**6.68E-05**	**1.43E+02**	

4.0 NORMALIZATION

The ANISN transport calculations used to develop the one-dimensional radial and axial neutron transport models are normalized to the greater than 1 MeV flux at the surveillance capsule. This normalization data is provided in References 1-4.

Detailed radiation profiles of the internals have yet to be obtained. Radiation profiles will be used to normalize the ORIGEN2 calculated radionuclide concentrations previously presented in this report. WMG intends to use the forthcoming radiation level measurements in conjunction with QAD-CGGP-A (Reference 10) and MegaShield™ models to normalize the activation results. The normalization to empirical data provides a more realistic determination of the neutron flux levels and energy spectra at the locations of interest. WMG uses similar methodology to characterize routine irradiated hardware from operating nuclear power plants. In addition, this methodology has been used for all irradiated reactor vessel and internals disposed to date.

Although radiation profiles are not yet available, normalization to surveillance capsule flux data is reflected in the previously presented results. WMG benchmarked the Zion activation analysis results presented in this report (i.e., normalized to surveillance capsule data only) to those from Trojan and found consistency within 5%. Therefore, the preliminary results presented herein are adequate for planning purposes.

5.0 REFERENCES

1. Yanichko, S.E., et al., “Commonwealth Edison Co., Zion Unit No. 1 Reactor Vessel Radiation Surveillance Program,”, WCAP-8064, Westinghouse Electric Corporation, March 1973.

2. Yanichko, S.E., et al., “Commonwealth Edison Co., Zion Unit No. 2 Reactor Vessel Radiation Surveillance Program,”, WCAP-8132, Westinghouse Electric Corporation, May 1973.

3. Chicots, J.M. , et al., “Zion Units 1 and 2 Reactor Vessel Fluence and RTPTS Evaluations,”, WCAP-10962 Rev. 3, Westinghouse Electric Corporation, September 1991.

4. Anderson, S.L., et al., “ENDFB/VI Fluence Evaluation for Zion Units 1 and 2,” REAC-CWE-048, Westinghouse Electric Corporation, June 1996.

5. Posivak to Bentley letter, “Zion Units 1 and 2 Reactor Internals Surveys”, November, 2007

6. Evans, J.C., et al., NUREG 3474, Long-Lived Activation Products in Reactor Materials, Pacific Northwest Laboratories, August 1984

7. ORNL CCC-254, ANISN-ORNL One-Dimensional Discrete Ordinates Transport Code with Anisotropic Scattering, Oak Ridge National Laboratory, April 1991.

8. DLC-185, BUGLE-96, Coupled, 47-Neutron, 20 Gamma-Ray Cross Section Library derived from ENDF/B-VI for LWR Shielding and Pressure Vessel Dosimetry Applications, Oak Ridge National Laboratory Radiation Shielding Information Center, July 1999.

9. ORNL/CCC-371, ORIGEN 2.1, Isotope Generation and Depletion Code, Matrix Exponential Method, Oak Ridge National laboratory, May 1999.

10. ORNL CCC-645, QAD-CGGP-A, A Point Kernel Code System for Neutron and Gamma-Ray Shielding Calculations using the GP Buildup Factor, December 1995.