5.0 SHIELDING EVALUATION

5.1 DESCRIPTION OF DESIGN FEATURES

The 3-60B packaging consists of a lead and steel containment vessel that provides the necessary shielding for the various radioactive materials to be shipped within the package. (Refer to Section 1.2.3 for packaging contents.) Tests and analysis performed under chapters 2.0 and 3.0 have demonstrated the ability of the containment vessel to maintain its shielding integrity under normal conditions of transport. Prior to each shipment, radiation readings will be taken based on individual loadings to assure compliance with 10CFR71.47.

The package shielding is sufficient to satisfy the dose rate limit of 10CFR71.51(a) (2) which states that any shielding loss resulting from the hypothetical accident will not increase the external dose rate to more than 1000 mrem/hr at one meter from the external surface of the cask.

5.1.1 Shielding Design Features

The cask sidewall consists of an outer 1 1/4-inch thick steel shell surrounding 6 inches of lead and an inner containment shell wall of 3/4-inch thick steel. There is a 12 ga. SS 304 thermal shield around the cask body, which is ignored in the shielding evaluation.

The lid consists of several circular stainless steel plates, a total of 10.5” thick. The lid closure is made in a stepped configuration to eliminate radiation streaming at the lid/cask body interface.

The cask bottom has an outer 3-inch thick steel shell, a 5-inch lead shield layer, and a 3/4-inch inner containment layer.

Both ends of the cask are contained in polyurethane foam filled impact limiters. The impact limiters have a ½-inch steel base plate that is fixed to the cask ends.

Table 5.1
Cask Components

COMPONENT	MATERIAL	DENSITY (g/cc)	DIMENSIONAL TOLERANCE
Outer Shell	SS Type 304	7.94	Mill std
Shielding	Lead	11.34	+1/8”-0”
Lid	SS Type 304	7.94	Mill std
Inner Shell	SS Type 304	7.94	Mill std
Liner	Carbon steel	7.82	Mill std
Liner	Polyethylene	0.941	nominal
Impact Limiter Foam	Polyurethane	0.40	nominal

5.1.2 Maximum Radiation Levels

Tables 5.2 and 5.3 give Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) dose rates resulting from two content configurations, i.e., irradiated hardware in a steel liner and grossly dewatered dispersible solid (e.g., swarf) in a high integrity container (HIC). The dose rate listed is the “total response” plus two times the “fractional standard deviation (fsd)” from the SCALE output (Ref. 5-3). As the contents are restricted to “fissile exempt” materials, the source activity does not include neutron emitters. Maximum allowable dose rates given in 10CFR71 are shown in the tables for comparison. The cask is always shipped exclusive use. The cask is loaded vertically and transported horizontally. Top and bottom refer to the end surfaces of the cask and with top referring to the lid end.

Table 5.2
Summary of Maximum Radiation Levels
Irradiated Hardware

	Total Dose Rate (mrem/hr)						
	Package Surface		1 m from Surface		2 m from Vehicle*		Occupied Space
Condition	Side	Top/Bottom	Side	Top/Bottom	Side	Top/Bottom	(6m from Top or Bottom
NCT							
Calculated	73.6	36.1/9.5	N.A.	N.A.	6.6	3.0/0.8	0.5
Allowable	200	200	N.A.	N.A.	10.0	10.0	2
HAC							
Calculated	N.A.	N.A.	61.5	43.9/10.1	N.A.	N.A.	NA
Allowable	N.A.	N.A.	1000.0	1000.0	N.A.	N.A.	NA

Table 5.3
Summary of Maximum Radiation Levels
Swarf

	Total Dose Rate (mrem/hr)						
	Package Surface		1 m from Surface		2 m from Vehicle*		Occupied Space
Condition	Side	Top/Bottom	Side	Top/Bottom	Side	Top/Bottom	(6m from Top or Bottom
NCT							
Calculated	67.6	46.5/13.0	N.A.	N.A.	7.7	3.8/1.0	0.6
Allowable	200	200	N.A.	N.A.	10.0	10.0	2
HAC							
Calculated	N.A.	N.A.	634	295/77.7	N.A.	N.A.	NA
Allowable	N.A.	N.A.	1000	1000	N.A.	N.A.	NA

- The 2m dose rates for the top and bottom of the cask are at 2m from the surface not from the vehicle.

5.2 Source Specification

The 3-60B cask is designed for transport of Type B quantities of high gamma activity radioactive material typically consisting of irradiated metal components, dispersible solids typified by irradiated metal cutting debris (swarf), dewatered resins, solidified process wastes, and other similar items. Two bounding contents configurations were analyzed:

1) a steel liner (34” OD, 108” L) of irradiated stainless steel reactor control rod blades (irradiated hardware). A hardware liner normally has a thick wall (1” or greater) but for the purpose of the shielding calculation geometry, the wall is assumed to be ½” carbon steel. The amount of irradiated hardware is assumed to be the maximum contents or 9,500 lbs, minus the weight of the liner.

2) a “high integrity container” (HIC) (34” OD, 108” L) of a grossly dewatered dispersible solid (irradiated stainless steel cutting debris or swarf). For the purpose of the shielding calculation geometry, the HIC wall is assumed to be ½”. The HIC material is polyethylene, thus providing minimal shielding. The amount of swarf is assumed to be the maximum contents or 9,500 lbs, minus the liner weight.

5.2.1 Gamma Source

The gamma source in each configuration is conservatively assumed to be ^{60}Co with an activity at the maximum for a Category II packaging, i.e., 30,000 Ci of ^{60}Co.

Photon Energy	Intensity
MeV	**Photons/sec**
0.6938	1.81e+011
1.1732	1.11e+015
1.3325	1.11e+015
Totals	**2.22e+15**

5.22 Neutron Sources

There are no sources of neutron radiation in the radioactive materials to be carried in the 3-60B cask.

5.3 Model Specification

5.3.1 Configuration of Source and Shielding

The source and liner configurations are given in Section 5.2
The dimensions of the cask axial and radial shielding elements are given in Table 5.4

Table 5.4
Model Shielding Elements

Component	Material	Outer Diameter (in)	Thickness (in)
Cavity	(void)	35	109.375 (length)
Inner Radial Shell	SS 304	36.5	0.75
Radial Shield	Lead	48.5	6
Outer Radial Shell	SS 304	51	1.25
Impact Limiter (axial)	Poly	82	18
Inner Axial Shell (lid)	SS 304	37	0.5
Axial Shield (lid)	SS 304	36	6
Outer Axial Shell (lid)	SS 304	48.75	4
Inner Axial Shell (bottom)	SS 304	36.5	0.75
Axial Shield (bottom)	Lead	48.5	5
Outer Axial Shell (bottom)	SS 304	51	3

The transport trailer is 8' wide and the cask will always be shipped "exclusive use". Thus, the dose point locations will include points 2m from the edge of the trailer.

Surface and point detectors in SAS4 are used to determine the doses from the cask. Point detectors were located at points of expected maximum dose rates. The default locations were used for the surface detectors for the models evaluating the NCT except that the second surface detector was set to the surface of the impact limiter. The radial locations of interest are at the cask surface and at 2m from the edge of the trailer, i.e. 322 cm. The axial locations of interest are at the cask surface, at 2m, and at the expected occupied area of the tractor while in transit (6m). When evaluating doses under HAC, surface and point detectors are placed at 1m from the surface. In all cases, the surface detectors are subdivided into small units so that maximums due to irregularities in the design can be detected. Where both point and surface detector results were obtained from the same location, the higher result was used unless the fsd was unacceptably large, i.e., greater than 0.25.

The normal conditions of transport (NCT) shielding models are shown in Figures 5.1 (top) and 5.2 (bottom).

Figure 5.1
3-60 Cask Top

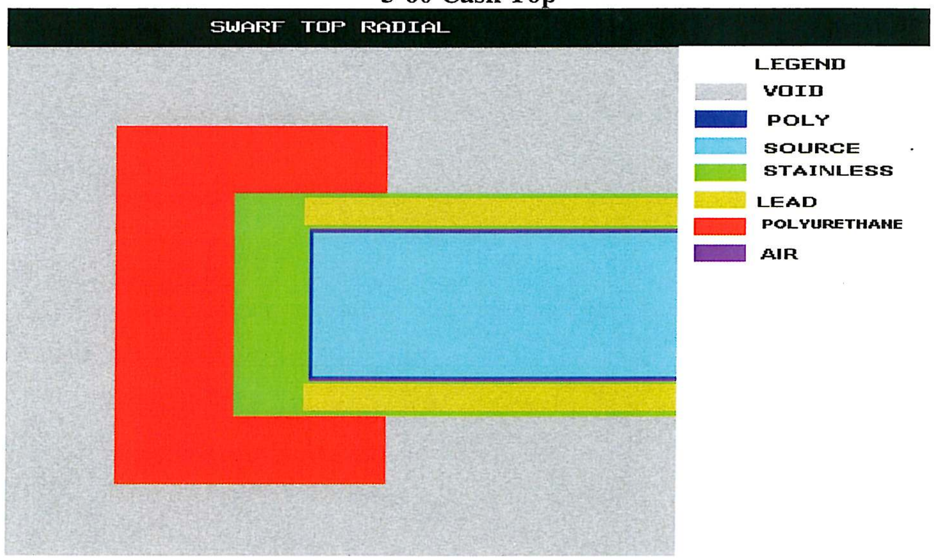
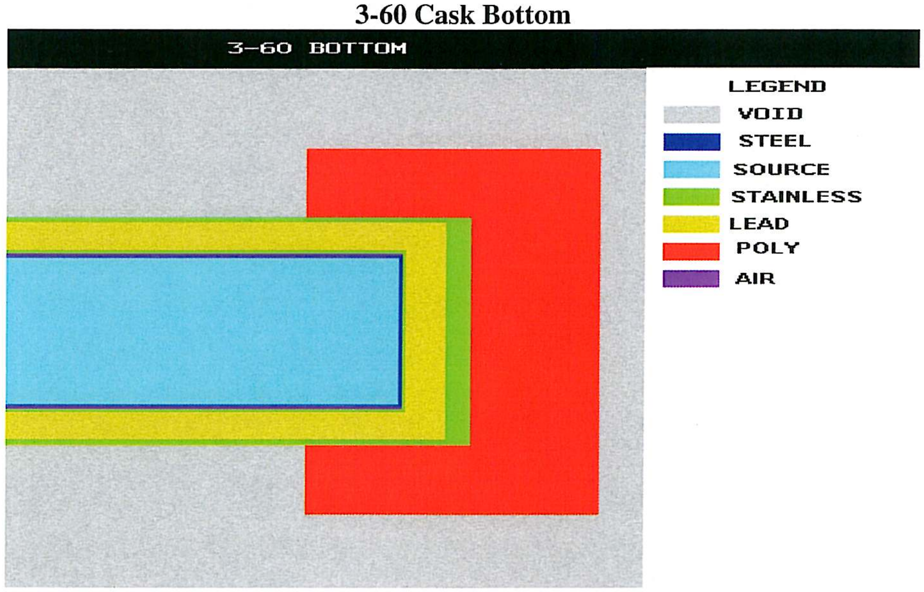


Figure 5.2
3-60 Cask Bottom



Under NCT, the material in the liner is assumed to be uniformly distributed over the liner interior cavity. For irradiated hardware, the calculated weight of the ½" liner is 1,858 lbs. With a payload maximum of 9,500 lbs., this gives a weight of hardware of 7,642 lbs. for a mass density of 2.309 g/cc. For swarf, the calculated weight of the HIC is 222 lbs, giving a resulting mass density of 2.803 g/cc. The swarf is assumed to have a porosity of 50%, so the dewatered swarf will contain equal volumes of swarf and water. The shielding effect of the water is conservatively ignored.

Under HAC, there are some changes to the cask configuration that are incorporated into the models. The drop analysis shows the impact limiters will remain in place but there will be some deformation. To conservatively determine the 1m dose rate after the drop, the impact limiters are removed from the model, except for the ½" top plate, which remains in place, and the dose point is set at 1m from the cask outer shell. This configuration covers the result of the puncture test by assuming the hole caused by the puncture bar reaches all the way to the cask outer shell. As discussed in Chapter 2, the puncture test does not cause any loss of shielding or create a streaming path. Also as noted in Chapter 2, there is a slump in the lead side shield as a result of the 30' drop onto the bottom of the cask creating a 0.81cm void at the top of the side shield.

The configuration of the irradiated hardware does not change, i.e., the shape and mass density stays the same. The forces on the contents, as determined in Chapter 2, are not large enough to deform the hardware.

For swarf, the material is assumed to compress as a result of the drop as shown in Figures 5.3 and 5.4. Assuming a liner 90% full of dewatered swarf, if the swarf were to compress to the normal density of stainless steel, the compressed source height would be ~76 cm. To conservatively assess a concentrated source, the size of the compressed source is assumed to be a cylinder with the diameter of the liner and a height of 20 cm. However, this compressed source is conservatively assumed to have a density less than steel, i.e., 6 g/cc, which reduces self-shielding, and has a specific activity of 0.045 Ci/g. This source is positioned at the top or bottom of the liner.

Figure 5.3
3-60 Cask Top (HAC)

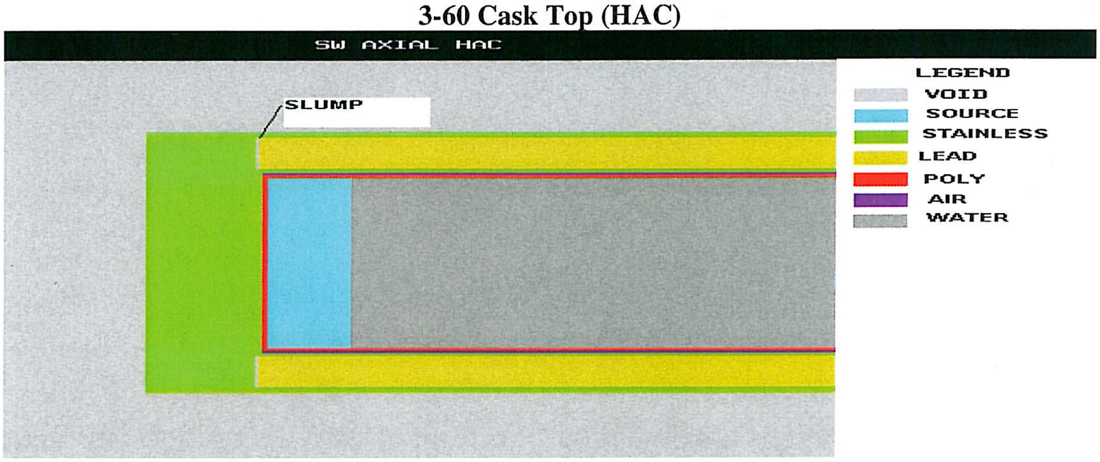
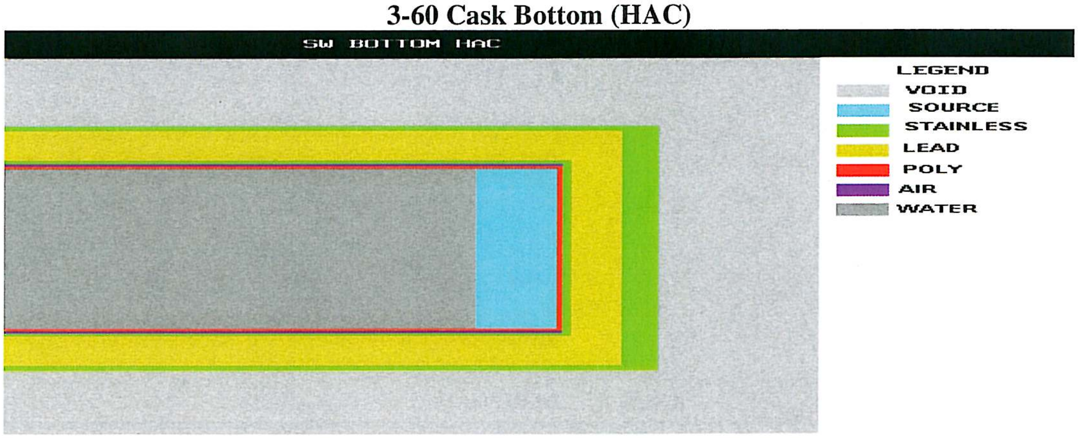


Figure 5.4
3-60 Cask Bottom (HAC)



The properties of the shield materials are given in Table 5.1. The stainless steel of the contents is assumed to be Type 316 with densities for the various configurations as given in 5.3.1.

5.4 Shielding Evaluation

5.4.1 Methods

The shielding evaluation is performed using the SAS4 module of the SCALE system (Ref. 5-1). The SAS4 control module performs a three-dimensional Monte Carlo shielding analysis of a radioactive material transport or storage container using an automated biasing procedure. Biasing parameters required by the Monte Carlo calculation are generated from results of a one-dimensional adjoint discrete-ordinates calculation. SAS4 performs resonance self-shielding treatment with either the BONAMI or NITAWL-II functional module and cell weighting with the XSDRNPM functional module; then it carries out adjoint discrete-ordinates and Monte Carlo calculations, respectively, with the XSDRNPM and MORSE-SGC functional modules.

The NCT calculations were setup in SAS4 with the simplified geometry input option (IGO=0) using the ESPN (Easy Shielding Processor Input) graphical user interface. Since SAS4 models only half the cask at a time and in either the radial or axial direction, multiple models are required. Since the cask top and bottom are different, axial models for both the top and bottom are needed, as well as a radial model, for each source configuration. Therefore, eight models were evaluated for NCT.

The HAC calculations were setup in SAS4 with the simplified geometry input option (IGO=0). As noted for the NCT models, eight models were evaluated for HAC. The SAS4 system requires that the source be axially symmetrical around the midpoint of the cask. To model a 20 cm disc source at the end of the cask, the source was set as the fuel hardware (316 stainless, ρ=6 g/cc). The activity of the source has to be doubled to get a correct output dose rate at the ends of the cask because the code assumes that hardware is located at the top and bottom of the fuel. The fuel was set as water to account for the water squeezed out of the dewatered swarf as it compressed.

5.4.2 Input and Output Data

The key inputs to SCALE are the cask materials, the cask geometry, and the source. SAS4 geometry input is referenced to the cask mid-plane, i.e., the origin, 0,0,0 point, is set at the midpoint (axially and radially) of the cask.

The source term is defined by the SOE, source energy spectrum array, and the SFA, source normalization factor. The SOE is defined as the percent of total gamma intensity in each energy group with the groups specified by the selected cross section library (27n-18couple). The intensity of the gammas, at energy E, are normalized to the average energy (E_{ave}) of the energy group for the source being evaluated by direct multiplication by the factor E/E_{ave}. The modeled source is 30 kCi of Co-60 (see Section 5.2.1), which has three gammas. The highest energy gamma, E=1.332, is just on the boundary between energy groups 36 and 37. One-half the initial intensity is applied to each of these two groups and then normalized. The middle energy gamma, E=1.173, is entirely normalized in Group 37. This procedure maintains the conservation of energy rather than photon intensity, which gives a more correct computation of dose rates. The low energy gamma, E= 0.6938, is not included as it has no appreciable impact on the dose calculation due to its low energy and intensity compared to that of the other two gammas. The resulting SOE has a distribution of 22% in group 36 and 78% in group 37. The SFA equals the total intensity of 2.247E+15 photons per second, normalized as described above from a 30 kCi Co-60 source. For the swarf HAC cases, the SFA is doubled, as discussed above, to 4.494E+15 photons per second.

In SAS4, the gamma source is expected to be spent fuel with photons originating in the fuel or the hardware. For modeling the 3-60B, the photon location was set as the fuel for most cases. For the HAC swarf case, to model the compressed source at the ends of the cask cavity, the gamma source is placed in the hardware as a 20 cm thick disk, as discussed above, and the gamma intensity is doubled.

The number of source particles, nst, and number of batches, nit, is adjusted until the dose rate results have a small fractional standard deviation (fsd), typically less than 0.1. The dose rate reported is the "total response" plus two times the "fsd" from the SCALE output. If there are both point and surface detector results for the same location, the higher value is reported unless the fsd for that vaule is too large, i.e., greater than 0.25. Table 5.5 gives the primary geometry input parameters for the radial calculation for the top half of the cask containing swarf. The input files and output files are included as Appendix 5.5.2.

Table 5.5
Geometry Parameters

Component	**Material**	**Radius (cm)**	**Height (from midpoint)(cm)**
Fuel	SS 316	41.91	135.88
Hardware	SS 316	41.91	135.89
Liner (insert)	Poly	43.18	137.15
Cavity	Air	44.45	137.16
Inner Shell	SS 304	46.36	138.11
Radial Shield	Lead	61.60	138.75
Axial Shield	SS 304	46.36	163.83
Outer Shell	SS 304	64.77	165.10*
Impact Limiter	Poly	104.14	107.95/209.55**

- includes ½" impact limiter attachment plate
** - lower and upper limits of the impact limiter

5.4.3 Flux-to-Dose-Rate Conversion

Flux-to-dose-rate conversion factors on the SCALE cross-section libraries are applied in the ultimate calculation of the desired gamma and neutron dose rates predicted for the case. The conversion factors, specified by IRF=9504, are those derived (in multigroup format) from the American National Standard Institute Neutron and Gamma-Ray Flux-to-Dose-Rate Factors (Ref. 5-2).

Table 5.6 - Gamma-Ray-Flux-To-Dose-Rate Conversion Factors

Photon Energy-E (MeV)	$DF_g(E)$ (Rem/hr)/(photons/cm^2-s)
0.01	3.96-06
0.03	5.82-07
0.05	2.90-07
0.07	2.58-07
0.1	2.83-07
0.15	3.79-07
0.2	5.01-07
0.25	6.31-07
0.3	7.59-07
0.35	8.78-07
0.4	9.85-07
0.45	1.08-06
0.5	1.17-06

Photon Energy-E (MeV)	$DF_g(E)$ (Rem/hr)/(photons/cm^2-s)
0.55	1.27-06
0.6	1.36-06
0.65	1.44-06
0.7	1.52-06
0.8	1.68-06
1.0	1.98-06
1.4	2.51-06
1.8	2.99-06
2.2	3.42-06
2.6	3.82-06
2.8	4.01-06
3.25	4.41-06
3.75	4.83-06
4.25	5.23-06
4.75	5.60-06
5.0	5.80-06
5.25	6.01-06
5.75	6.37-06
6.25	6.74-06
6.75	7.11-06
7.5	7.66-06
9.0	8.77-06
11.0	1.03-05
13.0	1.18-05
15.0	1.33-05

5.4.4 External Radiation Levels

The maximum dose rates under NCT for each of the source configurations, irradiated hardware and swarf, on the side, top, and bottom of the cask and the output files containing these results are shown in Table 5.7 The dose rate listed is the "total response" plus two times the "fsd" from the SCALE output. The surface dose rates on the top and bottom are on the outer flat surface of the impact limiter. The surface dose rates for the side is on the cylindrical cask surface which includes the impact limiter outer surface. The 2m locations on top and bottom are for a detector 2m outward from the impact limiter surface. The 2m side locations are 2m from the edge of the 8' wide trailer. The normally occupied space (driver location) is more than 6m from the end of the cask and is conservatively set at 6m.

Table 5.7
NCT Maximum Dose Rates

	Surface	**2m**	**6m**	**SAS4 file**
Irradiated Hardware				
Top	36.1	3.0	0.5	HWtopAxialR2.out
Bottom	9.5	0.8	0.1	HWbottomAxialR2.out
Side	73.6	6.6*	NA	HWtopRadialR2.out *HWbottomRadialR2.out
Swarf				
Top	46.5	3.8	0.6	SWtopAxialR2.out
Bottom	13.0	1.0	0.2	SWbottomAxialR2.out
Side	67.6	7.7	NA	SWtopRadialR2.out

The maximum dose rates under HAC for each of the source configurations are shown in Table 5.8. For the hardware source, the change to the geometry from that of the NCT models is to include the lead slump in the side shield and to remove the impact limiters. The swarf source changes geometry under HAC so the dose rates reported for top, bottom, and side are from HAC models that include the compressed source and lead slump and have the impact limiters removed.

Table 5.8
HAC Maximum Dose Rates at 1 meter from Package

Irradiated Hardware	**Dose Rate (mrem/hr)**	**SAS4 file**
Top	43.9	HWtopAxialHACR2.out
Bottom	10.1	HWbottomAxialR2HAC.out
Side	61.5	HWtopRadialHACR2.out
Swarf	**Dose Rate (mrem/hr)**	**SAS4 file**
Top	295	SWtopAxialHACR2.out
Bottom	77.7	SWbottomAxialHACR2.out
Side	634	SWTopRadialHACR2.out

As shown in Tables 5.7 and 5.8, the external dose rates for the 3-60 cask comply with the limits specified in 10 CFR 71.47 and 71.51.

5.5 Appendix

5.5.1 References

5-1 *SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluations,* NUREG/CR-0200, Rev.6 (ORNL/NUREG/CSD-2/R6), Vols. I, II, III, May 2000

5-2 *American National Standard Neutron and Gamma-Ray Flux-to-Dose Rate Factors*, ANSI/ANS-6.1.1-1977, American Nuclear Society, LaGrange Park, Illinois, 1977

5-3 SCALE Input and Output Files for 3-60B, EnergySolutions, 2008