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Shielding Analysis of the 5320 Shipping Cask

by

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REVISION 0

SHIELDING ANALYSIS OF THE 5320 SHIPPING CASK

May 1998

Westinghouse Savannah River Company
Project Engineering & Construction Division
Aiken, SC 29808

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1.0 Introduction

The purpose of this work is to demonstrate that the 5320 shipping cask meets Federal regulations for maximum radiation dose rates when loaded with the intended plutonium oxide cargo. It should be emphasized that the 5320 is an existing cask, and therefore this work represents confirmatory analysis rather than design analysis.

A shielding analysis of the 5320 cask was performed in 1995 (Reference 1) to support Rev. 4 of the SARP (Reference. 2). Questions raised by reviewers at Lawrence Livermore National Laboratory led to the decision to do a new shielding analysis. The reviewers raised five major issues that could not be answered without performing a new analysis:

1. The relative source height of 7.48 cm corresponds to a payload source mass and density of 357 g and 11.46 g/cm^3 , respectively. In Section 5.2 the text states that a payload mass of 819.3 g was analyzed. The corresponding relative source height for a payload source mass and density of 819.3 g and 11.46 g/cm^3 , respectively, is calculated to be 14.26 cm. Which payload source mass is correct? [This issue also appears on Pg. 5.5.1-33, Section 5.5 Appendix, Section 2.3 MARS Geometry, Section 2.3.1 Single Cask Geometry, Figure 6.]
2. The cap void diameter of 7.04 cm differs from the value of 6.27 cm given on the Dwgs. W2022907 and R-R1-H-0107. In addition, some axial separations cannot be verified from the drawings. There is 0.48 cm of stainless steel between the axial elevations of 37.79 cm and 38.27 cm that cannot be identified on the drawings. Indicate the drawing dimensions on the figure and discuss the effect of the difference between the drawing dimensions and the figure dimensions on the results of the shielding analysis. [These issues also appear on Pg. 5.5.1-34, Section 5.5 Appendix, Section 2.3 MARS Geometry, Section 2.3.1 Single Cask Geometry, Figure 7.]
3. The pressure fitting diameters of 2.29 cm and 1.27 cm given in the figure are less than the 2.54 cm and 1.43 cm given in Dwgs. W2021341 and R-R4-H-0181. What is the effect of the difference in the pressure fitting diameters on the results of the shielding analysis? [These issues also appear on Pg. 5.5.1-34, Section 5.5 Appendix, Section 2.3 MARS Geometry, Section 2.3.1 Single Cask Geometry, Figure 8.]
4. The effect of ground scatter appears to have been omitted from the calculations of dose rate for exclusive use transport. Provide a justification for omission of the ground scatter component or modify the calculations appropriately.
5. The text states that the ORIGEN-S neutron source can be conservatively used in the analyses. The neutron source presented as final in Table 7, however, is based on the SOURCES results. Furthermore, from Table 6, the ORIGEN-S, ANISNSRC, and SOURCES neutron sources are dominant in Bugle-80 energy groups 1 to 16, 17 to 23, and 24 to 35, respectively. Thus it is not clear that the use of ORIGEN-S is conservative. Please address. What was used in the MORSE calculations?

A new shielding analysis was performed. However, in the new analysis, the results of the previous work were used to guide the analysis.

The results of the shielding analysis are formally documented in this technical report. This report includes all details pertinent to the analysis. It is not written in the format required for a SARP chapter. The SARP chapter should be based on this report, should reference this report, and should include this report as an attachment.

2.0 Regulatory Requirements

The Department of Transportation (DOT) grants the Department of Energy (DOE) the authority to evaluate, approve, and certify packages used for the transportation of radioactive materials against packaging standards equivalent to those specified in 10 CFR Part 71 (49 CFR 173.7(d)). The requirements applicable to shielding are detailed in 10 CFR 71.47 and 10 CFR 71.51. 10 CFR 71.4 is also applicable, as it defines two key terms: Exclusive Use and Transport Index. These definitions are quoted here:

Exclusive Use (also referred to in other regulations as "sole use" or "full load") means the sole use of a conveyance by a single consignor and for which all initial, intermediate, and final loading and unloading are carried out in accordance with the direction of the consignor or consignee.

Transport Index means the dimensionless number (rounded up to the first decimal place) placed on the label of a package to designate the degree of control to be exercised by the carrier during transportation. The Transport Index is determined as follows:

- (1) The number expressing the maximum radiation level in millirem per hour at 1 meter from the external surface of the package; or
- (2) For Fissile Class II packages, the number expressing the maximum radiation level in millirem per hour at 1 meter from the external surface of the package, or the number obtained by dividing 50 by the allowable number of packages which may be transported together as determined under 10 CFR 71.59, whichever number is larger.

[Note: the 5320 package is rated Fissile Class I.]

10 CFR 71.47 is titled "External Radiation Standards for All Packages." It states that the radiation dose rate at the surface of a package cannot exceed 200 mrem/hr at any point on the external surface of the package, and the Transport Index must not exceed 10. However, an exception is granted if the package is to be shipped "Exclusive Use." In this case, the limit at the accessible external surface is 1000 mrem/hr, provided (1) the shipment is made in a closed transport vehicle, (2) the packages are secured such that they don't move during transport, and (3) there are no loading and unloading operations between the beginning and end of the transportation. In addition to the 1000 mrem/hr limit at the accessible surface, the following criteria must be met: (1) the radiation dose rate at any point on the external surface of the transport vehicle must not exceed 200 mrem/hr; (2) the dose rate at any point 2 meters from the outer lateral surfaces of the

transport vehicle must not exceed 10 mrem/hr; and (3) if the dose rate at any normally occupied position within the transport vehicle exceeds 2 mrem/hr, the personnel must be provided with health supervision, personnel radiation dose monitors, and special training.

10 CFR 71.51 is titled "Additional Requirements for Type B Packages." It requires that the radiation dose rate not exceed 1000 mrem/hr at a distance of one meter from the external surface of the package under hypothetical accident conditions.

2.1 Radiation Dose Rate Limits for the 5320

From the above discussion, the radiation dose rate limits that must be met for the 5320 are as follows:

Under Normal Conditions of Transport (NCT):

1. The radiation dose rate at the accessible surface of the package must not exceed 1000 mrem/hr;
2. The radiation dose rate at any external surface of the conveyance must not exceed 200 mrem/hr;
3. The radiation dose rate at any point 2 meters from the external lateral surface of the conveyance must not exceed 10 mrem/hr;
4. The radiation dose rate at any normally occupied position in the conveyance must be calculated. If it exceeds 2 mrem/hr, training and monitoring of personnel must be performed.

Under Hypothetical Accident Conditions:

1. The radiation dose rate at a distance of 1 meter from the external surface of the package must not exceed 1000 mrem/hr.

3.0 Analysis

The radiation dose rate at various locations around the 5320 cask was calculated using the MORSE [3] module of the SCALE code system. All MORSE calculations were performed with the photon source below 0.1 MeV zeroed out. This increases calculation efficiency without any sacrifice of accuracy since source photons below 0.1 MeV do not contribute to the dose outside the EP-62 secondary containment vessel. This is demonstrated by one-dimensional calculations using the SAS-1 module of SCALE 4.3 in which cases were run with the full photon source spectrum and with the groups below 0.1 MeV zeroed out. The resulting doses were 3.84887E+02 rem/hr with all groups and 3.83786E+02 rem/hr with the groups below 0.1 MeV zeroed out. The difference is less than 0.3% which is within the fractional standard deviation of the MORSE calculations.

3.1 Source Term

This section discusses the methodology for generating the neutron and photon source terms. The previous analysis examined two methodologies for calculating sources. The first, developed at SRS, was the methodology of choice at SRS for earlier cask analyses. That methodology is not only cumbersome, but also it has an additional drawback in that it relies on several "in-house" computer codes that outside reviewers are not familiar with. The second method used the industry-standard ORIGEN-S code. This section discusses the combining of these two methodologies into a single conservative source.

3.1.1 Methodology

The 5320 package is designated to carry plutonium oxide with initial isotopic distribution limited to that shown in Table 1. The previous shielding analysis (Reference 1) analyzed decay times up to 18 years. Because of the high ^{238}Pu content, the magnitude of the generated neutron field (from (α, n) reactions in ^{17}O and ^{18}O) is significant. The following sources of photons and neutrons must be considered:

1. Photons from the decay of the plutonium isotopes as well as the actinide impurity isotopes.
2. Photons released from (α, n) and spontaneous fission reactions.
3. Neutrons from (α, n) and spontaneous fission reactions.

The previous analysis conservatively assumed that all isotopes listed in Table 1 were present at their maximum weight percent. The use of the maximum permitted weight percents of each actinide isotope, leading to a source mass in excess of 100% the permitted mass, was done because no optimization analysis had been performed to find what combination of isotopes within the permitted envelope would yield the most limiting source term.

Reference 1 compared the photon and neutron sources computed using Health Physics Technology Section codes and ORIGEN-S. These codes are described briefly below:

ORIGEN2 (Reference 4) is a widely used code for performing nuclide irradiation and decay calculations. It was developed at Oak Ridge National Laboratory.

ANISNSRC (Reference 5) is a computer code developed at SRS specifically for determining the magnitude and spectra of the neutron and photon source emanating from plutonium compounds. No actinides other than Pu are considered in the calculation, and the plutonium compounds are assumed to be present in stoichiometric ratios at full theoretical density.

SOURCES (Reference 6) is a computer code originally written by Bill Wilson of Los Alamos National Laboratory. A copy of the code was obtained by HPT, and some modifications have been made for its use at SRS. This code was used to calculate the magnitude and energy spectrum of the neutron and photon fields resulting from

spontaneous fission and (α ,n) reactions. Edits are provided by isotope and for the total composition.

GAMSRC (Reference 7) is a computer code written at SRS to calculate the magnitude and energy spectrum of the photon field from nuclide decay. Edits are provided by isotope and for the total composition.

For the plutonium oxide payload to be carried in the 5320, the above codes are executed in the following sequence. First, the isotopic composition of the material as listed in Table 1, minus the plutonium isotopes, is input to the ORIGEN2 code, and is decayed. The resulting composition (actinides and their daughters, where actinides excludes plutonium) is input to the GAMSRC code, from which the decay gammas are calculated. GAMSRC performs its calculations using two independent data libraries: one based on the Table of Radioactive Isotopes (Reference 8) and one based on ICRP 38 (Reference 9). The user can then select the photon source from whichever library provides the more conservative result. Next, the plutonium isotopes are input to ANISNSRC, which calculates ALL gammas originating from the plutonium isotopes, including those from decay, (α ,n) and spontaneous fission sources. The total photon source is the sum of the ANISNSRC and GAMSRC results. ANISNSRC also calculates the neutron source from (α ,n) and spontaneous fission events. However, recall that only contributions from plutonium isotopes are accounted for in ANISNSRC. For this reason, the SOURCES code is run next, in order to calculate the neutron field from (α ,n) and spontaneous fission events, accounting for ALL isotopes present in the composition. The neutron fields from ANISNSRC and SOURCES can then be compared. The results from SOURCES are expected to be more accurate, since the non-plutonium isotopes are accounted for.

The release of SCALE 4.2 (Reference 10) and the ORIGEN-S code, introduced the possibility for performing all source term calculations with a single code. ORIGEN-S has been greatly improved over ORIGEN2.

In the previous work, both the traditional HPT methodology and the ORIGEN-S method were implemented and compared. That comparison concluded that ORIGEN-S can be conservatively used as a single tool for source term generation.

The SARP reviewers questioned the validity of that conclusion since ORIGEN-S neutron sources were not higher than the HPT methodology sources for all energy groups. The current analysis revised the neutron source term on a group by group basis (using the previously calculated sources) by selecting the maximum alpha-n neutron source from SOURCES or ORIGEN-S and combining it with the maximum spontaneous fission neutron source from SOURCES or ORIGEN-S. This results in a source term that is obviously conservative.

3.1.2 Results

The previous analysis found the decay time (between 0 and 18 years) that gives the limiting source. It concluded that the most limiting photon source occurs at 18 years

decay time and the most limiting neutron source occurs with zero years decay. To form the most limiting source term, the photon source at 18 years is combined with the neutron source at 0 years. In the remainder of this report, the photon source refers to the source at 18 years decay, while the neutron source refers to that at 0 years decay.

The photon source from actinide decay as calculated by GAMSRC is listed in Table 2 in the BUGLE-80 (Reference 11) group structure. As discussed above, GAMSRC uses two independent data bases and compares the results. The ICRP 38 library results in a higher total photon source, but this is due almost entirely to photons in the two lowest energy groups (below 30 keV). These photons are stopped by the containment vessel walls, and thus are not important in the analysis. The source term provided by the TORI library is harder, so that result is used in the analysis.

The plutonium photon source consists of three components: decay photons, photons from (α,n) reactions, and photons from spontaneous fissions. These are calculated using ANISNSRC. Table 3 presents the photon source term from the plutonium decay gammas as calculated by ANISNSRC and by GAMSRC. The comparison between the two codes is quite good. The ANISNSRC results were used for formulating the final source term.

The photons from spontaneous fission and (α,n) reactions were also calculated using ANISNSRC, and are presented in Table 4.

The final photon source term was compiled as follows. The component of the source due to spontaneous fission (calculated in ANISNSRC) was increased to account for neutron multiplication. The photons from the (α,n) reactions are also multiplied, but the resulting spectrum is from spontaneous fission. Therefore, the spontaneous fission photon source (also calculated in ANISNSRC) is increased according to the following formula:

$$G'_{sf} = G_{sf} \times M + G_{\alpha,n} \times (M - 1)$$

Where: G'_{sf} represents the photons from spontaneous fission after correction for neutron multiplication, G_{sf} is the same quantity before correction for neutron multiplication, $G_{\alpha,n}$ is the photon source from (α,n) reactions, and M is the neutron multiplication. The neutron multiplication was calculated to be 1.33 for NCT conditions and 10 for HAC (corresponding to the maximum k-eff values of 0.25 and 0.90 found in the criticality analysis (Reference 12)).

A second minor correction was made when compiling the final photon source. The (α,n) photon source calculated by ANISNSRC does not include any contribution that may be made by the non-plutonium isotopes. To correct for this, the ANISNSRC (α,n) photon source is multiplied by the ratio of the total neutron source calculated by SOURCES to that calculated by ANISNSRC (recall that SOURCES accounts for all α -emitters). The final photon source calculated by the HPT methodology consists of the spontaneous fission and (α,n) components from ANISNSRC, corrected as discussed above, summed

with the photon source from plutonium isotope decay (from ANISNSRC) and that from non-plutonium actinide decay (from GAMSRC). This source term is listed in Table 5.

The neutron source term calculated from SOURCES, ANISNSRC, and ORIGEN-S is listed in Table 6. The final neutron source term was obtained by selecting the maximum from the SOURCES and ORIGEN-S results for alpha-n and spontaneous fission reactions. This was adjusted to account for neutron multiplication for both NCT and HAC conditions and is given in Table 7. Note that under HAC conditions, a maximum k-eff of 0.90 was found in the criticality analysis (Reference 12). This results in a neutron multiplication factor of 10.

3.2 Materials

The 5320 shipping package consists of four nested main components: the EP-60 product canister, the EP-61 Primary Containment Vessel, the EP-62 Secondary Containment Vessel, and the cooling fin shell with thermal shield. The product canister and both containment vessels are constructed of various types of stainless steel, which are detailed in Reference 12. For the purposes of the shielding analysis, all of the steel is assumed to be stainless steel type 304. Only 5 other types of material need to be modeled for the 5320: air, aluminum, water extended polyester, concrete, and the source. The SS304, air, and concrete are present in the BUGLE 80 library as standard materials. The WEP composition used is identical to that used in the criticality analysis, the derivation of which is discussed in detail in Reference 12.

The isotopes considered in the plutonium oxide payload were given in Table 1. Of the isotopes listed, BUGLE 80 has cross sections for only the following: ^{235}U , ^{238}U , ^{239}Pu , and ^{240}Pu . To construct a source material model with only these isotopes, the other isotopes were treated as being one of the four isotopes mentioned above. The fissile isotopes U-233 and Pu-241 were treated as U-235 and Pu-239, respectively. The non-fissile actinides with an atomic number less than or equal to that of uranium were treated as U-238, while the remaining isotopes were treated as Pu-240. Table 9 lists the atom densities used in the source model. The assumption was made that there are two oxygen atoms present for each actinide atom. The density of the source material (2.56 g/cc) used to calculate these atom densities were calculated by dividing the payload mass by the EP-60 volume.

The BUGLE-80 (Reference 11) multigroup cross section set was used in modeling the 5320 shipping package. Table 10 lists the isotopes included in the MORSE model, with the corresponding BUGLE 80 ID numbers. Table 11 describes the media assignments.

3.3 MARS Geometry

3.3.1 Single Cask Geometry

Figure 1 is a drawing of the complete 5320 shipping cask assembly. The MORSE model was constructed on a unit basis, starting with the EP-60 Product Canister. Consistency with the KENO V.a model used in the criticality analysis was maintained whenever possible. Figures 2, 3, 4, and 5 show the modeling of the EP-60, EP-61, EP-62, and the shield tank. On these figures, the black numbers with the yellow background identify the MORSE bodies. All bodies except 10, 27, and 34 are cylinders oriented along the z-axis. Body 10 is a truncated right cone, body 27 a sphere, and body 34 a rectangular parallelepiped. The color of the body indicates the material used in the model. Blue represents SS304, white is air, red is the source, pink is the water extended polyester, and green is aluminum. The models were derived from blueprints (References 13, 14, 15, and 16). Note in Figure 5 that the aluminum cooling fins, the thermal shield, the cage (personnel barrier), and the impact limiter are not modeled, although the location of the latter two items is identified as the accessible external surface of the package. Also, on Figures 4 and 5, the orange numbers along the outside of the package identify HAC and NCT detector locations, respectively. On Figures 2-5, all dimensions are indicated in centimeters. The caster wheels are not included in the model, but it is noted that the distance from the bottom of the base plate to the floor is 5 inches when the casters are attached.

The plutonium oxide source material was modeled at three different locations: top, middle, and bottom of the EP-60 corresponding to possible placement of a full density powder ($\rho=11.46$ g/cc). The latter of these configurations is the one shown in Figure 2. The height of the source (7.48 cm) corresponds to a Pu mass of 357 g (405 g of oxide). This is the mass limit for the package. The source material was also modeled filling the EP-60 corresponding to a low-density powder. This results in four different NCT models. In all of the models, the source material was conservatively modeled as air.

For HAC, only the EP-60, EP-61, and EP-62 are modeled. Everything outside the secondary containment vessel is assumed to have been lost due to structural or fire damage. The accessible external surface is the external surface of the EP-62. The same four source material locations are modeled in the HAC analysis as in the NCT analysis. Also, as in the NCT analysis, the source material was conservatively modeled as air. Figure 4 shows the detector locations around the EP-62 for the HAC analysis.

3.3.2 Geometry for Exclusive Use Calculations

Preliminary calculations indicated the 5320 would not meet the requirements of 10 CFR 71 for an unrestricted shipment. Therefore, the 5320 must be shipped as exclusive use, and must meet the requirements of 10 CFR 71 for an exclusive use shipment. This means that the dose rate on the external surfaces of the conveyance, as well as in the driver's position, must be calculated. The conveyance used for 5320 shipments is the Safe Secure

Transport (SST). No more than twenty 5320 packages are loaded into the SST for a shipment. Figures 6 and 7 are schematics of the SST trailer loaded with twenty 5320 packages. The 5320 is secured in place via tie down brackets, which provide a spacing of 16.5 inches in the direction of the trailer width and 6 inches in the direction of the trailer length. These spacings are from the edge of the 5320 base plate. The first four feet of the SST trailer contains various equipment, so no 5320 package can be placed closer than 4 feet to the front end of the trailer. Figures 6 and 7 indicate locations of the trailer walls, floor and top, as well as the front equipment bay. The trailer walls, floor and top were conservatively modeled as $\frac{1}{2}$ inch of stainless steel [Reference 17]. The effects of ground scatter were included by placing a three-inch thick concrete slab beneath the trailer. The source for exclusive use calculations was modeled as a low-density powder distributed throughout the EP-60. The minimum density of the source material (2.56 g/cc) was calculated by dividing the payload mass by the EP-60 volume.

The figures are used to identify the placement of the 5320 packages within the trailer, and the location of the trailer outer surfaces and the cab. The dimensions shown in Figures 6 and 7 and discussed in this paragraph were obtained from Reference 18. Figures 6 and 7 also identify the detector locations used to find the dose rate at the external side, top, and bottom surfaces, as well as at 2 meters from the lateral surface. The darkened circles represent the source term locations. The dose rate at the centerline of all packages consists of contributions from all 20 packages. One method of finding this value would be to perform 20 different calculations, with the source modeled in each of the 20 different package locations. This would be an extremely time consuming and inefficient effort. Alternatively, 20 different detector locations, properly selected, can be used to find the collective dose in a single run. In practice, only 10 locations are needed for lateral surface calculations and only 5 for top and bottom surface calculations due to symmetry. The situation is somewhat different for the calculation of the dose rate in the cab. It is necessary to model five different source locations with two detector locations each, as indicated in Figure 8. This is because the front two packages have a direct path to the detector location, while the others are shielded by packages in front of them.

The dose rate at the necessary locations are calculated as sums of the values found at the various detector locations as follows:

$$\text{Dose Rate at Lateral Surface} = 2 * \text{sum}(a1:a10)$$

$$\text{Dose Rate at 1 Meter from Lateral Surface} = 2 * \text{sum}(d1:d10)$$

$$\text{Dose Rate at Top} = 4 * \text{sum}(c1:c5)$$

$$\text{Dose Rate at Bottom} = 4 * \text{sum}(b1:b5)$$

$$\text{Dose Rate in Cab} = 2 * \text{sum}(e1:e10)$$

4.0 Results

4.1 NCT Results

Tables 12 and 13 summarize the results of the NCT analysis at the cask surface and at 1 meter from the cask surface, respectively. The dose rate is reported for 15 detector locations (identified in Figure 5) and four source locations (high-density powders at the top, middle, and bottom of the EP-60, and a low-density powder evenly distributed throughout the EP-60). The dose rates reported are the calculated values increased by 3 standard deviations to account for statistical uncertainties. Some of the dose rates reported in Table 12 exceed the 200 mrem/hr limit for a package shipped as a non-exclusive use package. However, all of the dose rates in Table 12 are less than the 1000 mrem/hr limit permitted for an exclusive use package.

For a package to be shipped non-exclusive use, the radiation dose rate 1 meter from the package surface must be less than 10 mrem/hr (actually, the requirement is for a transport index that doesn't exceed 10). As can be seen from Table 13, the 5320 would meet this requirement, as the maximum dose rate found at 1 meter was 9.6 mrem/hr. The data in Table 13 are used in the calculation of the Transport Index. The Transport Index for the 5320 cask with the payload defined in Table 1 is 10.

Tables 14-17 present details of the results summarized in Table 12. Note that in these tables, fsd is an abbreviation of fractional standard deviation. The calculated dose rate is divided into contributions from neutrons and photons, and the fractional standard deviation is provided. Calculations were run for a coupled neutron-photon problem with the neutron source and a photon only problem. From these, the neutron dose rate (including secondary photon contributions) and the photon dose rate were found. From Tables 14-17, it can be seen that the neutron dose dominates the total calculated dose rate at the top and bottom of the cask, and accounts for about half of the total dose rate in the radial direction. The much greater dominance of the dose rate in the axial directions than in the radial directions arises for two reasons: (1) there is no WEP at the top or bottom of the cask to shield the neutrons; (2) there is more steel at the top and bottom to shield the photons.

4.2 HAC Results

The results of the HAC analysis are summarized in Table 18. As in Tables 12 and 13, the dose rates are reported at a $+3\sigma$ level for four different source positions and 7 detector locations (identified in Figure 4). The dose rates are well below the 1000 mrem/hr limit in 10 CFR 71.51. Tables 19 - 22 present details of the HAC results. Note that for HAC conditions, the dose rate at all positions is due almost entirely to the neutrons. This is because (1) there is no WEP neutron shielding and (2) a k-eff of 0.90 (neutron multiplication of 10) was used in the HAC analysis (compare this to the k-eff of 0.25, or neutron multiplication of 1.33, used in the NCT analysis).

4.3 Exclusive Use Results

The results of the exclusive use calculations are summarized in Table 23 and detailed in Table 24. The calculated dose rate at all points except the rear of the cab is less than the 10 CFR 71 limits. Since the calculated dose rate in the cab exceeds 2 mrem/hr, personnel must be provided with health supervision, personnel radiation dose monitors, and special training as described in 10 CFR 71.

5.0 Summary and Conclusions

A bounding shielding analysis for the 5320 cask has shown that the requirements of 10 CFR 71 for radiation dose rate limits are met under both normal and hypothetical accident conditions, IF the 5320 packages are shipped exclusive use in the Safe, Secure Transport, with no more than twenty 5320 casks per shipment. Because the dose rate in the cab as calculated exceeds 2 mrem/hr, personnel must receive special training and wear personnel radiation dosimeters. These conclusions are based on an extremely conservative shielding analysis. The conservative assumptions included the following:

1. The plutonium oxide payload carried in the 5320 is specified with allowable maximum ranges of the various isotopes. In the specification developed in this work, all isotopes were assumed to be present at their maximum amount, such that a total payload mass of 819 grams was used, as compared to the allowed mass of 357 grams plutonium.
2. The neutron source was taken at 0 years decay time, where it is at a maximum, while the photon source was taken at 18 years decay time, when it is a maximum. Clearly, only one of these maxima can be realized at any one time.
3. The HAC model is extremely conservative. It assumes total loss of the WEP neutron shield, and all aluminum structural components.
4. The walls, structural material, *etc.*, in the SST were modeled as ½ inch stainless steel in the exclusive use calculations.

6.0 References

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15. Finned Cask Details, Drawing W2022908, Rev. 0, 7-17-92.
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TABLE 1

Composition of Plutonium Oxide Shipped in the 5320

Isotope	Allowed Range of Composition†, %	Composition Analyzed, %	Composition Analyzed, grams
Th-232	=10	10	35.7
Pa-231	=0.5	0.5	1.785
U-233	=0.5	0.5	1.785
U-235	=0.5	0.5	1.785
U-236	=0.5	0.5	1.785
U-238	=0.5	0.5	1.785
Np-237	=0.5	0.5	1.785
Pu-236	=0.0001	0.0001	0.000357
Pu-238	=100 (=7)	100	357
Pu-239	=100 (=5)	100	357
Pu-240	=13 (=25)	13	46.41
Pu-241	=1 (=10)	1	3.57
Pu-242	=1.5 (=65)	1.5	5.355
Am-241	=1	1	3.57
Total		229.5	819.32

†The numbers in parentheses are the limits for a $^{242}\text{PuO}_2$ product. The non-Pu actinide limits for this product are the same as those for the $^{238}\text{PuO}_2$.

TABLE 2

Non-Pu Actinide Decay Photons from GAMSRC

Bugle 80 Group #	Actinide Decay Gammas from GAMSRC		Ratio Table/ICRP 38
	ICRP 38	TORI	
48			
49			
50			
51			
52			
53			
54			
55	4.32E+04	4.32E+04	1.00
56	3.72E+04	3.52E+04	0.95
57	1.76E+06	2.90E+06	1.65
58	4.24E+07	5.60E+07	1.32
59	1.25E+07	1.75E+07	1.40
60	2.39E+06	3.85E+06	1.61
61	1.77E+08	1.95E+08	1.10
62	1.43E+09	1.37E+09	0.95
63	3.32E+08	3.21E+08	0.97
64	1.16E+09	1.20E+09	1.03
65	1.58E+11	1.58E+11	1.00
66	4.31E+10	3.37E+10	0.78
67	2.53E+11	1.54E+11	0.61
Total	4.57287E+11	3.49436E+11	0.76

TABLE 3

Plutonium Decay Gammas from ANISNSRC and GAMSRC

Bugle 80 Group #	ANISNSRC	GAMSRC		ANISNSRC/ ICRP38	ANISNSRC/ TORI
		ICRP38	TORI		
48					
49					
50					
51	2.1610e+03				
52	6.4743e+03				
53	1.9396e+04				
54	5.8409e+04				
55	8.6336e+07	8.86e+07	8.87e+07	1.0	1.0
56	5.5942e+06	9.03e+06	4.99e+06	0.6	1.1
57	7.2091e+06	6.32e+06	5.25e+06	1.1	1.4
58	2.5050e+07	3.20e+07	1.76e+08	0.8	0.1
59	1.1177e+08	1.27e+08	1.12e+08	0.9	1.0
60	2.3989e+06	9.81e+05	1.88e+06	2.4	1.3
61	1.1104e+08	1.13e+08	1.13e+08	1.0	1.0
62	2.2498e+08	2.29e+08	2.25e+08	1.0	1.0
63	2.2745e+09	2.38e+09	2.40e+09	1.0	0.9
64	1.4581e+10	1.55e+10	1.50e+10	0.9	1.0
65	1.6973e+11	1.70e+11	1.70e+11	1.0	1.0
66	2.2742e+12	2.55e+12	2.27e+12	0.9	1.0
67	1.9208e+13	1.96e+13	1.93e+13	1.0	1.0
Total	2.17e+13	2.23e+13	2.18e+13	1.0	1.0

TABLE 4

Photons from Spontaneous Fission and (α ,n) Reactions

Bugle 80 Group #	S.F. Gammas	Alpha-n Gammas
	From ANISNSRC	
48		
49		
50		
51	2.1610e+03	
52	6.4743e+03	
53	1.9396e+04	
54	5.8109e+04	2.9901e+02
55	2.6447e+05	6.0228e+04
56	4.2303e+05	3.7080e+05
57	6.0313e+05	1.3951e+06
58	5.5296e+05	
59	4.2745e+05	
60	5.2597e+05	
61	1.1878e+06	
62	9.6856e+05	2.6950e+06
63	3.3757e+05	
64	1.0598e+05	
65	8.1722e+04	
66	2.7682e+04	
67	2.7907e+04	
Total	5.6204e+06	4.5215e+06

TABLE 5

Final Photon Source

Bugle 80	Energy Bound (MeV)		Photon Source (p/sec)	
Group #	Upper	Lower	NCT	HAC
48	1.40E+01	1.00E+01	0.0000E+00	0.0000E+00
49	1.00E+01	8.00E+00	0.0000E+00	0.0000E+00
50	8.00E+00	7.00E+00	0.0000E+00	0.0000E+00
51	7.00E+00	6.00E+00	2.8813E+03	2.1610E+04
52	6.00E+00	5.00E+00	8.6324E+03	6.4743E+04
53	5.00E+00	4.00E+00	2.5861E+04	1.9396E+05
54	4.00E+00	3.00E+00	7.7878E+04	5.8408E+05
55	3.00E+00	2.00E+00	8.6487E+07	8.9301E+07
56	2.00E+00	1.50E+00	5.8940E+06	1.2774E+07
57	1.50E+00	1.00E+00	1.0775E+07	2.8093E+07
58	1.00E+00	8.00E-01	8.1234E+07	8.6027E+07
59	8.00E-01	7.00E-01	1.2941E+08	1.3312E+08
60	7.00E-01	6.00E-01	6.4242E+06	1.0983E+07
61	6.00E-01	4.00E-01	3.0644E+08	3.1673E+08
62	4.00E-01	2.00E-01	1.5962E+09	1.6280E+09
63	2.00E-01	1.00E-01	2.5956E+09	2.5985E+09
64	1.00E-01	6.00E-02	1.5781E+10	1.5782E+10
65	6.00E-02	3.00E-02	3.2773E+11	3.2773E+11
66	3.00E-02	2.00E-02	2.3079E+12	2.3079E+12
67	2.00E-02	1.00E-02	1.9362E+13	1.9362E+13
Total			2.2018E+13	2.2018E+13
Total above 0.1 MeV			4.8186E+09	4.9044E+09

TABLE 6

Comparison of Neutron Source Term as Calculated by SOURCES, ANISNSRC, and ORIGIN-S

Bugle 80 Group #	Alpha-n Neutrons	Spont. Fiss. Neutrons	Alpha-n Neutrons	Spont. Fiss. Neutrons	Alpha-n Neutrons	Spont. Fiss. Neutrons
	From ANISNSRC		From SOURCES		From ORIGIN-S	
1	0.0000e+00	1.6923e+01	0.0000e+00	1.6747e+01		
2	0.0000e+00	9.0311e+01	0.0000e+00	9.1841e+01		1.36E+02
3	0.0000e+00	6.6502e+02	0.0000e+00	6.6388e+02		1.19E+03
4	0.0000e+00	1.8042e+03	0.0000e+00	1.7979e+03		1.83E+03
5	0.0000e+00	4.5030e+03	0.0000e+00	4.4980e+03		5.81E+03
6	2.7747e-05	1.4109e+04	1.4720e-05	1.4040e+04		1.76E+04
7	4.6581e+03	2.9011e+04	4.8612e+03	2.8938e+04		3.50E+04
8	2.3214e+05	8.0460e+04	2.2940e+05	8.0525e+04	1.88E+05	9.04E+04
9	7.1900e+05	7.7577e+04	7.1284e+05	7.7964e+04	8.21E+05	8.32E+04
10	4.7657e+05	4.4182e+04	4.5912e+05	4.3140e+04	6.77E+05	4.29E+04
11	4.7137e+05	4.6593e+04	4.6545e+05	4.6626e+04	6.88E+05	4.94E+04
12	1.9741e+05	1.9916e+04	1.9317e+05	1.9738e+04	2.69E+05	2.14E+04
13	3.9029e+04	3.9990e+03	3.9274e+04	4.0716e+03	5.22E+04	4.27E+03
14	2.3109e+05	2.4153e+04	2.3905e+05	2.5323e+04	3.05E+05	2.50E+04
15	6.1308e+05	7.2790e+04	6.0260e+05	7.2638e+04	8.04E+05	7.51E+04
16	4.9837e+05	7.1125e+04	4.9568e+05	7.1868e+04	5.52E+05	7.41E+04
17	5.4352e+05	8.8573e+04	5.3500e+05	8.8842e+04	4.53E+05	9.72E+04
18	4.7336e+05	1.1352e+05	4.6253e+05	1.1332e+05	3.20E+05	1.31E+05
19	1.8789e+05	6.1239e+04	1.8206e+05	6.0341e+04	8.94E+04	6.65E+04
20	6.9891e+04	2.6398e+04	6.8860e+04	2.6369e+04	2.85E+04	3.18E+04
21	1.0546e+05	4.5039e+04	1.0449e+05	4.5159e+04	3.50E+04	5.69E+04
22	7.2177e+04	3.5818e+04	7.1373e+04	3.5756e+04	2.31E+04	4.56E+04
23	6.6936e+04	3.9692e+04	6.6599e+04	3.9679e+04	1.72E+04	5.29E+04
24	2.3620e+04	2.0422e+04	2.3759e+04	2.0532e+04	9.28E+03	2.75E+04
25	2.0411e+04	2.8939e+04	2.0614e+04	2.8922e+04	3.84E+03	
26	7.3387e+03	1.5028e+04	7.5102e+03	1.5012e+04	2.43E+03	
27	2.9963e+03	7.3124e+03	3.6526e+03	8.7140e+03	3.74E+02	
28	1.2928e+03	3.5146e+03	7.8272e+02	2.0930e+03		
29	3.3802e+02	9.9293e+02	3.5626e+02	9.9947e+02		
30	1.8654e+02	5.6789e+02	1.9317e+02	5.6102e+02		
31	5.6440e+01	1.7288e+02	5.9790e+01	1.7468e+02		
32	6.6338e+01	2.0259e+02	6.9598e+01	2.0265e+02		
33	1.7878e+02	5.3978e+02	1.8919e+02	5.4432e+02		
34	1.6550e+02	4.8433e+02	1.7298e+02	4.8206e+02		
35	5.6033e+01	1.5772e+02	5.8890e+01	1.5782e+02		

TABLE 7

Final Neutron Source Term

Bugle 80 Group #	Energy Bound (MeV)		Final Source (n/sec)	
	Upper	Lower	NCT	HAC
1	1.7E+01	1.4E+01	2.2329E+01	1.6747E+02
2	1.4E+01	1.2E+01	1.8133E+02	1.3600E+03
3	1.2E+01	1.0E+01	1.5867E+03	1.1900E+04
4	1.0E+01	8.6E+00	2.4400E+03	1.8300E+04
5	8.6E+00	7.4E+00	7.7467E+03	5.8100E+04
6	7.4E+00	6.1E+00	2.3467E+04	1.7600E+05
7	6.1E+00	5.0E+00	5.3148E+04	3.9861E+05
8	5.0E+00	3.7E+00	4.2640E+05	3.1980E+06
9	3.7E+00	3.0E+00	1.2056E+06	9.0420E+06
10	3.0E+00	2.7E+00	9.5987E+05	7.1990E+06
11	2.7E+00	2.5E+00	9.8320E+05	7.3740E+06
12	2.5E+00	2.4E+00	3.8720E+05	2.9040E+06
13	2.4E+00	2.3E+00	7.5293E+04	5.6470E+05
14	2.3E+00	2.2E+00	4.4000E+05	3.3000E+06
15	2.2E+00	1.9E+00	1.1721E+06	8.7910E+06
16	1.9E+00	1.6E+00	8.3480E+05	6.2610E+06
17	1.6E+00	1.4E+00	8.4293E+05	6.3220E+06
18	1.4E+00	1.0E+00	7.9137E+05	5.9353E+06
19	1.0E+00	8.2E-01	3.3141E+05	2.4856E+06
20	8.2E-01	7.4E-01	1.3421E+05	1.0066E+06
21	7.4E-01	6.1E-01	2.1519E+05	1.6139E+06
22	6.1E-01	5.0E-01	1.5596E+05	1.1697E+06
23	5.0E-01	3.7E-01	1.5933E+05	1.1950E+06
24	3.7E-01	3.0E-01	6.8345E+04	5.1259E+05
25	3.0E-01	1.8E-01	6.6048E+04	4.9536E+05
26	1.8E-01	1.1E-01	3.0030E+04	2.2522E+05
27	1.1E-01	5.7E-02	1.6489E+04	1.2367E+05
28	5.7E-02	4.1E-02	3.8343E+03	2.8757E+04
29	4.1E-02	3.2E-02	1.8076E+03	1.3557E+04
30	3.2E-02	2.6E-02	1.0056E+03	7.5419E+03
31	2.6E-02	2.4E-02	3.1263E+02	2.3447E+03
32	2.4E-02	2.2E-02	3.6300E+02	2.7225E+03
33	2.2E-02	1.5E-02	9.7801E+02	7.3351E+03
34	1.5E-02	7.1E-03	8.7339E+02	6.5504E+03
35	7.1E-03	3.3E-03	2.8895E+02	2.1671E+03
Total			9.3939E+06	7.0454E+07

TABLE 8

Composition of Water Extended Polyester

Material	wt. %	Chemical Composition	MW	Isotope	Atom Density atm/b-cm
Polyester	47.3	C ₁₀ H ₁₄ O ₄	198.2	C	2.3349e-02
Water	21.8	H ₂ O	18.02	H	6.1477e-02
Ethylene Glycol	22.2	C ₂ H ₆ O ₂	62.07	O	2.4113e-02
Boric Acid	7.2	H ₃ BO ₃	61.83	B-10	1.7444e-04
Sodium Hydroxide	1.5	NaOH	40.00	B-11	7.0214e-04
				Na	2.8229e-04

TABLE 9

Atom Densities for Source Material

Isotope	Atom Density (at/bn-cm)	Comments
O-16	1.1405e-02	
U-235	2.5197e-05	(includes U-233)
U-238	2.8610e-04	(includes Ac-227, Th-232, Pa-231, U-236)
Pu-239	2.5022e-03	(includes Pu-241)
Pu-240	2.8618e-03	(Includes Pu-236, Pu-238, Pu-242, Np-237, Am-241)

TABLE 10**BUGLE 80 ID Numbers for Isotopes Included in the Model**

Isotope	BUGLE 80 ID
H	1001
B-10	5010
O-16	8016
U-235	92235
U-238	92238
C-12	6012
Na	11023
Al-27	13027
Pu-239	94239
Pu-240	94240
Air	99002
SS-304	99005
Concrete	99003

TABLE 11**MORSE Media and Zone Assignments**

Media #	Material
1	SS-304
2	Air
3	Source
4	Al
5	WEP
6	Concrete

TABLE 12

NCT Dose Rates at Accessible Surface in mrem/hr

Detector #	Location	Source Location			
		Distributed	Top	Middle	Bottom
1	Radial	29	8	18	73
2		151	49	148	251
3		204	153	252	146
4		163	297	144	45
5	Bottom	50	10	30	155
6		13	4	5	24
7	Top	194	400	109	24
8		127	338	71	13
9		69	195	33	7
10		61	176	28	5
11		50	140	23	4
12		42	106	25	4
13		37	98	20	4
14		37	92	21	4
15		43	95	28	12

Requirement: 10 CFR 71.47, <1000 mrem/hr for an exclusive use shipment.
 (Highlighted values are the highest dose rate found for that detector location.)

TABLE 13

NCT Dose Rates 1 Meter from Accessible Surface in mrem/hr

Detector #	Location	Source Location			
		Distributed	Top	Middle	Bottom
1	Radial	6.1	5.7	5.9	6.5
2		6.8	7.0	6.6	6.8
3		7.0	7.6	6.8	6.7
4		7.0	8.1	6.7	6.4
5	Bottom	1.2	0.6	0.9	2.5
6		0.8	0.2	0.5	2.1
7	Top	7.4	8.8	7.0	6.5
8		7.2	8.8	6.8	6.2
9		6.9	8.9	6.3	5.6
10		5.8	9.6	4.8	3.8
11		4.6	8.7	3.2	2.3
12		3.8	8.6	2.6	1.2
13		3.4	8.0	2.0	0.6
14		3.1	7.5	1.9	0.5
15		3.7	7.6	2.7	1.5

Requirement: None for an exclusive use shipment.

TABLE 14

Detailed NCT Results with a Low Density Plutonium Oxide Powder Uniformly Distributed Throughout the EP-60

Detector #	Location	neutron	photon	total	fsd	total + 3 σ	% from Neutrons
1	Radial	8.6	18.1	26.8	0.033	29.4	32
2		57.7	86.0	143.7	0.016	150.7	40
3		79.0	116.8	195.9	0.014	204.2	40
4		71.5	84.5	156.0	0.016	163.4	46
5	Bottom	44.5	1.8	46.3	0.030	50.5	96
6		3.9	5.5	9.4	0.114	12.6	41
7	Top	93.5	65.4	158.9	0.073	193.5	59
8		95.0	26.9	121.9	0.014	126.9	78
9		57.6	9.4	67.0	0.009	68.8	86
10		51.9	7.7	59.6	0.008	61.0	87
11		42.3	6.2	48.5	0.008	49.7	87
12		36.8	4.0	40.8	0.008	41.8	90
13		32.5	3.5	36.0	0.010	37.0	90
14		32.1	3.5	35.6	0.011	36.7	90
15		36.9	4.8	41.6	0.009	42.7	89

TABLE 15

Detailed NCT Results with a High Density Plutonium Oxide Powder at the Top of the EP-60

Detector #	Location	neutron	photon	total	fsd	total + 3 σ	% from Neutrons
1	Radial	1.6	4.6	6.2	0.116	8.3	26
2		15.5	28.7	44.2	0.034	48.6	35
3		63.1	83.8	146.9	0.014	153.0	43
4		156.0	132.1	288.0	0.010	296.7	54
5	Bottom	7.8	0.9	8.7	0.050	10.0	90
6		0.7	1.1	1.8	0.321	3.6	38
7	Top	246.2	135.2	381.4	0.016	399.7	65
8		282.1	48.2	330.3	0.007	337.7	85
9		169.7	22.6	192.3	0.005	195.2	88
10		153.7	20.3	174.1	0.004	176.3	88
11		122.7	15.6	138.2	0.004	139.8	89
12		96.0	8.9	104.9	0.004	106.1	92
13		88.9	7.9	96.8	0.004	97.9	92
14		84.1	6.8	91.0	0.003	91.8	93
15		85.5	8.5	94.0	0.003	94.9	91

TABLE 16

Detailed NCT Results with a High Density Plutonium Oxide Powder Centered in the EP-60

Detector #	Location	neutron	photon	total	fsd	total + 3 σ	% from Neutrons
1	Radial	5.4	10.7	16.2	0.031	17.6	34
2		53.9	85.7	139.6	0.019	147.5	39
3		101.7	141.6	243.3	0.011	251.6	42
4		57.1	81.5	138.6	0.014	144.2	41
5	Bottom	25.7	1.0	26.7	0.038	29.7	96
6		1.9	2.1	4.0	0.055	4.6	47
7	Top	38.9	49.0	87.9	0.081	109.3	44
8		38.1	28.0	66.1	0.024	70.9	58
9		24.8	6.9	31.7	0.014	33.0	78
10		22.2	5.0	27.2	0.011	28.1	82
11		18.5	3.6	22.1	0.011	22.8	84
12		21.4	3.0	24.4	0.009	25.1	88
13		16.8	2.2	19.0	0.010	19.6	89
14		18.2	2.2	20.4	0.009	21.0	89
15		24.2	3.7	27.9	0.007	28.5	87

TABLE 17
Detailed NCT Results with a High Density Plutonium Oxide Powder at the Bottom
of the EP-60

Detector #	Location	neutron	photon	total	fsd	total + 3 σ	% from Neutrons
1	Radial	22.8	42.0	64.9	0.040	72.7	35
2		99.8	142.1	241.9	0.013	251.0	41
3		55.1	85.0	140.1	0.014	146.1	39
4		14.5	27.1	41.6	0.030	45.3	35
5	Bottom	134.7	7.8	142.5	0.030	155.3	94
6		12.0	9.7	21.7	0.041	24.4	55
7	Top	7.6	10.8	18.4	0.110	24.5	41
8		5.2	6.9	12.1	0.035	13.3	43
9		3.5	2.6	6.1	0.028	6.6	57
10		2.9	1.7	4.7	0.028	5.1	63
11		2.5	1.3	3.8	0.028	4.1	66
12		2.7	0.9	3.6	0.027	3.9	74
13		2.6	0.7	3.4	0.027	3.6	78
14		3.4	0.8	4.2	0.021	4.5	81
15		9.9	1.9	11.8	0.006	12.0	84

TABLE 18

Summary of Results of the HAC Analysis Dose Rates 1 Meter from Accessible Surface

Detector #	Location	Distributed	Top	Middle	Bottom
1	Bottom	11.2	8.5	17.9	9.9
2	Radial	163.7	161.8	167.3	162.3
3		165.1	163.9	172.7	158.5
4		162.9	162.1	171.8	154.2
5		154.2	153.9	163.1	144.8
6		147.5	147.6	157.0	135.8
7	Top	25.9	20.0	49.3	14.4

TABLE 19

Detailed HAC Results with a Low Density Plutonium Oxide Powder Uniformly Distributed Throughout the EP-60

Detector #	Location	neutron	photon	total	fsd	total + 3 σ	% From Neutrons
1	Bottom	10.8	0.2	11.0	0.008	11.2	98
2	Radial	150.9	11.5	162.4	0.003	163.7	93
3		152.1	11.7	163.8	0.003	165.1	93
4		150.1	11.5	161.6	0.003	162.9	93
5		142.1	10.8	152.9	0.003	154.2	93
6		136.1	10.2	146.2	0.003	147.5	93
7	Top	24.9	0.4	25.3	0.008	25.9	98

TABLE 20

Detailed HAC Results with a High Density Plutonium Oxide Powder at the Top of the EP-60

Detector #	Location	neutron	photon	total	fsd	total + 3 σ	% From Neutrons
1	Bottom	17.2	0.3	17.5	0.007	17.9	98
2	Radial	155.3	10.6	165.9	0.003	167.3	94
3		160.0	11.2	171.2	0.003	172.7	93
4		159.1	11.2	170.3	0.003	171.8	93
5		150.9	10.6	161.5	0.003	163.1	93
6		145.8	9.9	155.7	0.003	157.0	94
7	Top	47.6	0.8	48.4	0.006	49.3	98

TABLE 21

Detailed HAC Results with a High Density Plutonium Oxide Powder Centered in the EP-60

Detector #	Location	neutron	photon	total	fsd	total + 3 σ	% From Neutrons
1	Bottom	8.2	0.1	8.3	0.009	8.5	98
2	Radial	148.9	11.7	160.6	0.002	161.8	93
3		150.8	11.9	162.7	0.002	163.9	93
4		149.2	11.8	161.0	0.002	162.1	93
5		141.7	11.2	152.9	0.002	153.9	93
6		136.0	10.5	146.6	0.002	147.6	93
7	Top	19.2	0.4	19.5	0.008	20.0	98

TABLE 22

Detailed HAC Results with a High Density Plutonium Oxide Powder at the Bottom of the EP-60

Detector #	Location	neutron	photon	total	fsd	total + 3 σ	% From Neutrons
1	Bottom	9.5	0.2	9.7	0.008	9.9	98
2	Radial	148.9	12.1	161.0	0.003	162.3	92
3		145.8	11.5	157.3	0.003	158.5	93
4		141.9	11.1	153.0	0.003	154.2	93
5		133.4	10.3	143.8	0.002	144.8	93
6		125.3	9.5	134.8	0.003	135.8	93
7	Top	13.6	0.3	13.9	0.011	14.4	98

TABLE 23

Summary of Results of Exclusive Use Calculations

Location	Dose Rate	at +2s	at +3 σ	10 CFR 71 Limit
Lateral Surface	47.3	49.0	49.9	200
Lateral Surface + 2 meters	8.4	8.6	8.7	10
Bottom of Trailer Bed	49.5	53.2	55.0	200
Top of Trailer	15.7	16.2	16.4	200
Back of Cab	2.1	2.2	2.3	2

TABLE 24

Details of Results of Exclusive Use Calculations

Morse Detector #	Detector ID	Dose	fsd	Dose + 2 σ	Dose + 3 σ
1	a1	0.606	0.041	0.656	0.681
2	a2	1.937	0.022	2.021	2.063
3	a3	0.417	0.039	0.450	0.467
4	a4	0.407	0.053	0.450	0.472
5	a5	0.167	0.062	0.188	0.198
6	a6	10.676	0.014	10.969	11.115
7	a7	5.893	0.016	6.077	6.169
8	a8	2.300	0.019	2.386	2.429
9	a9	0.896	0.021	0.934	0.953
10	a10	0.359	0.020	0.374	0.381
11	d1	0.140	0.026	0.147	0.150
12	d2	0.244	0.020	0.254	0.258
13	d3	0.373	0.012	0.382	0.386
14	d4	0.157	0.019	0.163	0.166
15	d5	0.088	0.027	0.093	0.095
16	d6	0.812	0.012	0.831	0.840
17	d7	0.766	0.010	0.781	0.789
18	d8	0.661	0.011	0.676	0.683
19	d9	0.531	0.011	0.543	0.548
20	d10	0.421	0.025	0.443	0.453
21	c1	1.151	0.011	1.177	1.190
22	c2	0.972	0.012	0.996	1.007
23	c3	0.793	0.012	0.811	0.820
24	c4	0.580	0.017	0.600	0.610
25	c5	0.437	0.030	0.463	0.476
26	b1	5.625	0.041	6.089	6.321
27	b2	4.411	0.029	4.662	4.788
28	b3	1.661	0.034	1.775	1.831
29	b4	0.465	0.052	0.513	0.537
30	b5	0.216	0.085	0.253	0.271
1	e1	0.044	0.026	0.047	0.048
2	e2	0.032	0.023	0.034	0.035
1	e3	0.061	0.025	0.064	0.065
2	e4	0.025	0.024	0.027	0.027
1	e5	0.090	0.021	0.094	0.096
2	e6	0.020	0.024	0.021	0.021
1	e7	0.140	0.017	0.145	0.147
2	e8	0.017	0.029	0.018	0.018
1	e9	0.622	0.009	0.633	0.638
2	e10	0.016	0.028	0.017	0.017

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Figure 1 Schematic Of 5320 Shipping Cask

EP-60 Product Canister

All dimensions in cm.

Figure 2 EP-60 Product Container

Figure 3 EP-61 Primary Containment Vessel

Figure 4 EP-62 Secondary Containment Vessel

Cooling Fin Shell, Thermal Shield, and Base Plate

Note: Orange numbers denote detector locations.

Figure 5 Cooling Fin Shell, Thermal Shield, and Baseplate

Figure 6 Top View Schematic of SST Loaded With Twenty 5320 Packages

Figure 7 Side View Schematic of SST Loaded With Twenty 5320 Packages

Figure 8 Schematic of SST Showing Detector Locations For Cab Dose Assessment

APPENDIX A

INPUT FILES

At least 1 input deck is listed in this appendix for each of the computer codes utilized in the analysis. The files not included are very similar to the ones that are. The included files are marked with an asterisk in the list below. The others can be viewed electronically by contacting the author. Electronic copies of the output file are also maintained.

File	Configuration	Description
SAS-1		
hacsas*	HAC	One-dimensional calculation to demonstrate accuracy of dropping photon sources below 0.1 MeV
MORSE		
nct1*	NCT	High Density Source at bottom of EP 60 Neutrons
nct1g		High Density Source at bottom of EP 60 Photons
nct2		High Density Source centered in EP 60 Neutrons
nct2g		High Density Source centered in of EP 60 Photons
nct3		High Density Source at top of EP 60 Neutrons
nct3g		High Density Source at top of EP 60 Photons
nct4		Low Density Source distributed throughout EP 60 Neutrons
nct4g		Low Density Source distributed throughout EP 60 Photons
hac1	HAC	High Density Source at bottom of EP 60 Neutrons
hac1g*		High Density Source at bottom of EP 60 Photons
hac2		High Density Source centered in EP 60 Neutrons
hac2g		High Density Source centered in of EP 60 Photons
hac3		High Density Source at top of EP 60 Neutrons
hac3g		High Density Source at top of EP 60 Photons
hac4		Low Density Source distributed throughout EP 60 Neutrons
hac4g		Low Density Source distributed throughout EP 60 Photons
ldexn1*	Exclusive Use	Calculation for dose at top bottom, and lateral surfaces. High-density source centered in EP-60. Neutrons
ldexg1		Calculation for dose at top, bottom and lateral surfaces. High-density source centered in EP-60. Photons
stldcabn?		Calculation for neutron dose in cab. Source in row ?. (? = 1,2, ... 5)
stldcabg?*		Calculation for photon dose in cab. Source in row ?. (? = 1,2, ... 5)

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Input File *hacsas* for SAS1 one-dimensional calculation

```

=sasl      parm=size=500000
material for sasl hac conditions gamma run
27n-18couple      infhommedium
'air
arbm-air 1.10e-3 2 0 0 1 8016 18 7014 72 1 end
ss304 2 end
end comp
end

case 1, all source groups used
'geometry
cylindrical
1 1.302 10 -1 0 0 0.0 1.236e+13
2 2.1465 10 0
1 2.26 2 0
2 2.54 10 0
1 2.625 2 0
2 2.978 10 0
end zone
'source distribution
'total p/sec/basis: 0.12360e+14      basis = full payload m=10
27z
0.31965e-08 0.10408e-07 0.51608e-07 0.12076e-06 0.45302e-06 0.59292e-06
0.93329e-06 0.98471e-06 0.17999e-05 0.27262e-05 0.70714e-05 0.12913e-04
0.11350e-04 0.43352e-04 0.66771e-04 0.21229e-03 0.17827e-01 0.98181e+00
ndetec=0
read xsdose
27.15
end
last
case 1a, sources in groups 1 to 16 used
'geometry
cylindrical
1 1.302 10 -1 0 0 0.0 4.467e09sas
2 2.1465 10 0
1 2.26 2 0
2 2.54 10 0
1 2.625 2 0
2 2.978 10 0
end zone
'source distribution
'total p/sec/basis: 0.12360e+14      basis = full payload m=10
27z
0.31965e-08 0.10408e-07 0.51608e-07 0.12076e-06 0.45302e-06 0.59292e-06
0.93329e-06 0.98471e-06 0.17999e-05 0.27262e-05 0.70714e-05 0.12913e-04
0.11350e-04 0.43352e-04 0.66771e-04 0.21229e-03 2z
ndetec=0
read xsdose
27.15
end

```


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Input file *nct1* High Density Source at bottom of EP 60 Neutrons

```

=morse
nct biassing run neutron sources coupled
  4f861e50
1$$$ 0 1000 2500 10 1 0 1 0 0 0 0 0 0 0 e
2$$$ 5 9 0 16 0 e
3$$$ 47 20 0 0 0 0 0 4 2 67 0 0 0 0 0 0 78 0 0 3 e
4$$$ -1 67 0 0 e
5$$$ 1 47 67 0 0 1 34 4 4r0 1 2r0 1 1 f0 e
t
5320 nct conditions
0 0 1 0
  rcc 1 0 0 2.14 0 0 27.15 2.147
  rcc 2 0 0 2.14 0 0 5.34 1.302
  rcc 3 0 0 -2.52 0 0 4.66 1.854
  rcc 4 0 0 -0.07 0 0 2.21 0.997
  rcc 5 0 0 7.48 0 0 4.92 1.302
  rcc 6 0 0 29.29 0 0 2.21 0.997
  rcc 7 0 0 29.29 0 0 4.66 1.854
  rcc 8 0 0 -2.52 0 0 36.99 2.26
  rcc 9 0 0 -3.71 0 0 38.76 2.54
  trc 10 0 0 32.76 0 0 2.29 2.54 4.87
  rcc 11 0 0 35.73 0 0 2.06 0.955
  rcc 12 0 0 38.27 0 0 0.25 3.135
  rcc 13 0 0 35.05 0 0 4.83 4.287
  rcc 14 0 0 -3.71 0 0 0.30 0.955
  rcc 15 0 0 -7.52 0 0 36.51 2.625
  rcc 16 0 0 29.60 0 0 15.10 5.12
  rcc 17 0 0 -17.04 0 0 46.03 2.987
  rcc 18 0 0 28.99 0 0 16.32 5.715
  rcc 19 0 0 33.12 0 0 5.23 11.43
  rcc 20 0 0 -17.04 0 0 2.84 0.955
  rcc 21 0 0 42.60 0 0 3.81 1.590
  rcc 22 0 0 44.68 0 0 1.73 1.270
  rcc 23 0 0 43.57 0 0 1.11 0.715
  rcc 24 0 0 -17.43 0 0 45.72 3.035
  rcc 25 0 0 28.29 0 0 4.83 7.79
  rcc 26 0 0 33.12 0 0 16.19 16.19
  sph 27 0 0 49.31 16.19
  rcc 28 0 0 -17.43 0 0 44.77 3.65
  rcc 29 0 0 27.34 0 0 5.78 8.41
  rcc 30 0 0 32.17 0 0 0.95 20.64
  rcc 31 0 0 -17.43 0 0 49.60 16.19
  rcc 32 0 0 -16.47 0 0 43.81 15.29
  rcc 33 0 0 27.34 0 0 4.83 15.29
  rpp 34 -22.86 22.86 -25.40 25.40 -18.38 -17.43
  rpp 35 -1000. 1000. -1000. 1000. -1000. 1000.
  sph 36 3r0. 1e12
  rcc 37 0 0 12.4 0 0 6.64 1.302
  rcc 38 0 0 19.04 0 0 4.92 1.302
  rcc 39 0 0 23.96 0 0 5.33 1.302
end
stl +1 -2 -5 -37 -38 -39
src +4 or +2
air +5 or +37 or +38 or +39 or +6
air +8 -1 -3 -7 or +11 or +12 or +14 or +15 -9 -10 or +16 -10 -13 -21
-9 or +20 or +22 or +23 or +24 -17 or +25 -17 -18 or +26 -18
-19 -21 or +27 -26 -18 -19 -21 or +35 -34 -31 -30 -26 -27
stl +3 -4
stl +7 -6
stl +9 -8 -14
stl +10 -9 or +13 -11 -12
stl +17 -15 -20
stl +18 -16 -21 or +21 -22 -23
stl +19 -18
alm +28 -24
alm +29 -24 -25 -17 -18 or +30 -29
alm +31 -32 -33
wep +32 -28
wep +33 -29
stl +34
voi +36 -35

```

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```

end
  1 2 5 5 3 4 5 6 7 8 9 10 11 12 13 14 15 16
  18r0
  1 3 2 2 7r1 3r4 2r5 1 0
0
6** 180. 0. 9.39388e6 0. -1.302 1.302 -1.302 1.302 -0.07 31.51
11** 752r0.01
12$$ 1 2 3 4 5r5
13$$ 99005
      99002
      99002
      13027
      6012 1001 8016 5010 11023
14** 1.0
      1.0
      1.0
      6.026e-2
      2.3349e-2 6.1477e-2 2.4113e-2 1.7444e-4 2.8229e-4
17**
2.37701e-06 1.93034e-05 1.68904e-04 2.59744e-04 8.24651e-04
2.49808e-03 5.65776e-03 4.53913e-02 1.28339e-01 1.02180e-01
1.04664e-01 4.12183e-02 8.01515e-03 4.68390e-02 1.24776e-01
8.88664e-02 8.97322e-02 8.42435e-02 3.52797e-02 1.42873e-02
2.29071e-02 1.66027e-02 1.69613e-02 7.27552e-03 7.03096e-03
3.19672e-03 1.75527e-03 4.08169e-04 1.92427e-04 1.07047e-04
3.32798e-05 3.86419e-05 1.04112e-04 9.29740e-05 3.07590e-05
12r0.0
20r0.
t
dose rate at specified locations
dose rate, mrem/hr
fluence
19**
      20.64      0      -16.
20**
4.27e-01 3.86e-01 3.22e-01 2.94e-01 2.94e-01 2.98e-01 3.08e-01 2.94e-01
2.73e-01 2.60e-01 2.52e-01 2.50e-01 2.51e-01 2.51e-01 2.53e-01 2.55e-01
2.57e-01 2.61e-01 2.49e-01 2.32e-01 2.15e-01 1.95e-01 1.66e-01 1.29e-01
9.63e-02 6.10e-02 4.08e-02 2.73e-02 1.99e-02 1.67e-02 1.48e-02 1.37e-02
1.13e-02 7.98e-03 7.15e-03 7.31e-03 7.53e-03 7.90e-03 8.19e-03 8.52e-03
8.88e-03 9.12e-03 9.14e-03 9.00e-03 4.35e-03 4.03e-03 3.67e-03
1.03e-02 8.77e-03 7.75e-03 6.82e-03 6.21e-03 5.45e-03 4.67e-03 3.62e-03
2.97e-03 2.26e-03 1.83e-03 1.60e-03 1.44e-03 1.17e-03 7.19e-04 3.71e-04
2.66e-04 2.97e-04 8.27e-04 2.14e-03
21$$ 65i1 67
t
end

```

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Input file *hac1g* High Density Source at bottom of EP 60 Photons

```

=morse
hac biassing gamma gp 1-16 casel
4f861e50
1$$ 0 1000 2500 100 1 0 1 0 0 0 0 0 0 0 e
2$$ 5 9 0 16 0 e
3$$ 0 20 0 0 0 0 0 4 2 20 0 0 0 0 0 78 0 0 3 e
4$$ -1 20 0 0 e
5$$ 7 20 20 0 0 1 34 4 4r0 1.2r0 1 1 f0 e
t
5320 nct conditions
0 0 1 0
rcc 1 0 0 2.14 0 0 27.15 2.147
rcc 2 0 0 2.14 0 0 5.34 1.302
rcc 3 0 0 -2.52 0 0 4.66 1.854
rcc 4 0 0 -0.07 0 0 2.21 0.997
rcc 5 0 0 7.48 0 0 4.92 1.302
rcc 6 0 0 29.29 0 0 2.21 0.997
rcc 7 0 0 29.29 0 0 4.66 1.854
rcc 8 0 0 -2.52 0 0 36.99 2.26
rcc 9 0 0 -3.71 0 0 38.76 2.54
trc 10 0 0 32.76 0 0 2.29 2.54 4.87
rcc 11 0 0 35.73 0 0 2.06 0.955
rcc 12 0 0 38.27 0 0 0.25 3.135
rcc 13 0 0 35.05 0 0 4.83 4.287
rcc 14 0 0 -3.71 0 0 0.30 0.955
rcc 15 0 0 -7.52 0 0 36.51 2.625
rcc 16 0 0 29.60 0 0 15.10 5.12
rcc 17 0 0 -17.04 0 0 46.03 2.987
rcc 18 0 0 28.99 0 0 16.32 5.715
rcc 19 0 0 33.12 0 0 5.23 11.43
rcc 20 0 0 -17.04 0 0 2.84 0.955
rcc 21 0 0 42.60 0 0 3.81 1.590
rcc 22 0 0 44.68 0 0 1.73 1.270
rcc 23 0 0 43.57 0 0 1.11 0.715
rcc 24 0 0 -17.43 0 0 45.72 3.035
rcc 25 0 0 28.29 0 0 4.83 7.79
rcc 26 0 0 33.12 0 0 16.19 16.19
sph 27 0 0 49.31 16.19
rcc 28 0 0 -17.43 0 0 44.77 3.65
rcc 29 0 0 27.34 0 0 5.78 8.41
rcc 30 0 0 32.17 0 0 0.95 20.64
rcc 31 0 0 -17.43 0 0 49.60 16.19
rcc 32 0 0 -16.47 0 0 43.81 15.29
rcc 33 0 0 27.34 0 0 4.83 15.29
rpp 34 -22.86 22.86 -25.40 25.40 -18.38 -17.43
rpp 35 -1000. 1000. -1000. 1000. -1000. 1000.
sph 36 3r0. 1e12
rcc 37 0 0 12.4 0 0 6.64 1.302
rcc 38 0 0 19.04 0 0 4.92 1.302
rcc 39 0 0 23.96 0 0 5.33 1.302
end
stl +1 -2 -5 -37 -38 -39
src +4 or +2
air +5 or +37 or +38 or +39 or +6
air +8 -1 -3 -7 or +11 or +12 or +14 or +15 -9 -10 or +16 -10 -13 -21
-9 or +20 or +22 or +23 or +24 -17 or +25 -17 -18 or +26 -18
-19 -21 or +27 -26 -18 -19 -21
air +35 -34 -31 -30 -26 -27
stl +3 -4
stl +7 -6
stl +9 -8 -14
stl +10 -9 or +13 -11 -12
stl +17 -15 -20
stl +18 -16 -21 or +21 -22 -23
stl +19 -18
alm +28 -24
alm +29 -24 -25 -17 -18 or +30 -29
alm +31 -32 -33
wep +32 -28
wep +33 -29
stl +34

```

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```

voi      +36 -35
end
  1 2 5 5 16 3 4 5 6 7 8 9 10 11 12 13 14 15 15
19r0
  1 3 2 2 2 7r1 3r2 2r2 2 0
0
6** 180. 0. 4.9044E+09 0. -1.302 1.302 -1.302 1.302 -0.07 31.51
12$$ 1 2 3 4 5r5
13$$ 99005
      99002
      99002
      13027
      6012 1001 8016 5010 11023
14** 1.0
      1.0
      1.0
      6.026e-2
      2.3349e-2 6.1477e-2 2.4113e-2 1.7444e-4 2.8229e-4
17**
0.00000E+00 0.00000E+00 0.00000E+00 9.81456E-10 2.94042E-09
8.80903E-09 2.65271E-08 4.05578E-06 5.80147E-07 1.27590E-06
3.90705E-06 6.04574E-06 4.98795E-07 1.43849E-05 7.39363E-05
1.18017E-04 4Z
t
dose rate at specified locations
dose rate, mrem/hr
fluence
19**
      0      0 -117.04
    103.      0 3.71
    103.      0 18.
    103.      0 25.52
    105.      0 31.05
    105.      0 41.53
      0      0 145.31

20**
1.03e-02 8.77e-03 7.75e-03 6.82e-03 6.21e-03 5.45e-03 4.67e-03 3.62e-03
2.97e-03 2.26e-03 1.83e-03 1.60e-03 1.44e-03 1.17e-03 7.19e-04 3.71e-04
2.66e-04 2.97e-04 8.27e-04 2.14e-03
21$$ 18i1 20
t
end

```

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Input file *ldexn1* Exclusive Use. Calculation for dose at top, bottom, and lateral surfaces.
High density source centered in EP-60. Neutrons

```
=morse
eu neutrons coupled low density self shielded .5 in steel
  4f861e50
1$$ 0 1000 2500 200 1 0 1 0 0 0 0 0 0 0 e
2$$ 6 14 0 16 0 e
3$$ 47 20 67 0 0 0 0 4 2 67 0 0 0 0 0 0 78 0 0 3 e
4$$ -1 67 0 0 e
5$$ 30 0 0 0 0 1 34 4 4r0 1 2r0 1 1 f0 e
t
5320 nct conditions
0 0 1 0
rcc 1 0 0 2.14 0 0 27.150001 2.147
rcc 2 0 0 2.14 0 0 5.34 1.302
rcc 3 0 0 -2.52 0 0 4.660001 1.854
rcc 4 0 0 -0.07 0 0 2.21 0.997
rcc 5 0 0 7.48 0 0 4.92 1.302
rcc 6 0 0 29.29 0 0 2.21 0.997
rcc 7 0 0 29.29 0 0 4.66 1.854
rcc 8 0 0 -2.52 0 0 36.99 2.26
rcc 9 0 0 -3.71 0 0 38.760001 2.54
trc 10 0 0 32.76 0 0 2.290001 2.53999 4.287
rcc 11 0 0 35.73 0 0 2.06 0.955
rcc 12 0 0 38.27 0 0 0.25 3.135
rcc 13 0 0 35.05 0 0 4.83 4.287
rcc 14 0 0 -3.71 0 0 0.30 0.955
rcc 15 0 0 -7.52 0 0 37.12 2.625
rcc 16 0 0 29.60 0 0 15.10 5.12
rcc 17 0 0 -17.04 0 0 46.03 2.987
rcc 18 0 0 28.99 0 0 16.32 5.715
rcc 19 0 0 33.12 0 0 5.23 11.43
rcc 20 0 0 -17.04 0 0 2.84 0.955
rcc 21 0 0 42.60 0 0 3.81 1.590
rcc 22 0 0 44.68 0 0 1.73 1.270
rcc 23 0 0 43.57 0 0 1.11 0.715
rcc 24 0 0 -17.43 0 0 45.72 3.035
rcc 25 0 0 28.29 0 0 4.83 7.79
rcc 26 0 0 33.12 0 0 16.19 16.19
sph 27 0 0 49.31 16.19
rcc 28 0 0 -17.43 0 0 44.77 3.65
rcc 29 0 0 27.34 0 0 5.78 8.41
rcc 30 0 0 32.17 0 0 0.95 20.64
rcc 31 0 0 -17.43 0 0 49.60 16.19
rcc 32 0 0 -16.47 0 0 43.81 15.29
rcc 33 0 0 27.34 0 0 4.83 15.29
rpp 34 -22.86 22.86 -25.40 25.40 -18.38 -17.43
rpp 35 -30.48 30.48 -25.4 25.4 -18.38 65.51
sph 36 3r0. 1e12
rcc 37 0 0 12.4 0 0 6.64 1.302
rcc 38 0 0 19.04 0 0 4.92 1.302
rcc 39 0 0 23.96 0 0 5.33 1.302
rpp 40 -30.48 30.48 -8.89 8.89 -18.38 65.51
rpp 41 -30.48 30.48 -20.955 20.955 -18.38 65.51
rpp 42 -304.7999999999 304.7999999999
-089.5349999999 89.5349999999
-018.3799999999 65.5099999999
rpp 43 -2000. 2000. -2000.0 2000.0 -177.765 1000.000
rpp 44 -2000. 2000. -2000.0 2000.0 -185.385 -177.765
rpp 45 -2100. 2100. -2100.0 2100.0 -200. 1200.
rpp 46 -306.07 306.07 -90.804 90.804 -19.65 66.77
end
stl +1 -2 -5 -37 -38 -39
src +37
air +5 or +4 or +2 or +38 or +39 or +6
air +8 -1 -3 -7 or +11 or +12 or +14 or +15 -9 -10 or +16 -10 -13 -21
-9 or +20 or +22 or +23 or +24 -17 or +25 -17 -18 or +26 -18
-19 -21 or +27 -26 -18 -19 -21
air +35 -34 -31 -30 -26 -27
stl +3 -4
stl +7 -6
stl +9 -8 -14
```

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```

stl      +10 -9 or +13 -11 -12
stl      +17 -15 -20
stl      +18 -16 -21 -15 or +21 -22 -23
stl      +19 -18
alm      +28 -24
alm      +29 -24 -25 -17 -18 or +30 -29
alm      +31 -32 -33
wep      +32 -28
wep      +33 -29
stl      +34
un2      +36 -35
un1      +40
un1      +36 -40
un3      +41
un3      +36 -41
trl      +42
con      +44
air      +43 -46
voi      +36 -45
ext      +45 -43 -44
stl      +46 -42
end
  1 2 5 5 16 3 4 5 6 7 8 9 10 11 12 13 14 5 15 5 15 5 15 5 16 5 15 15 5
18r1 1 2 2 3 3 0 0 0 0 0 0
  1 3 2 2 2 7r1 3r4 2r5 1 -1000 2 -1000 2 -1000 -1 6 2 0 1000 1
10 5 1 0 0
10r2 10r1 10r3 10r1 10r2
0 1 1
6** 1000. 0. 9.39388e6 0. 28.078 31.782 -47.657 -45.053 -0.07 31.51
12$$ 1 2 5r3 4 5r5 6
13$$ 99005
      99002
      8016 92235 92238 94239 94240
      13027
      6012 1001 8016 5010 11023
      99003
14** 1.0
      1.0
      1.1405e-2 2.5197e-5 2.861e-4 2.5022e-3 2.8618e-3
      6.026e-2
      2.3349e-2 6.1477e-2 2.4113e-2 1.7444e-4 2.8229e-4
      1.0
17**
2.37701e-06 1.93034e-05 1.68904e-04 2.59744e-04 8.24651e-04
2.49808e-03 5.65776e-03 4.53913e-02 1.28339e-01 1.02180e-01
1.04664e-01 4.12183e-02 8.01515e-03 4.68390e-02 1.24776e-01
8.88664e-02 8.97322e-02 8.42435e-02 3.52797e-02 1.42873e-02
2.29071e-02 1.66027e-02 1.69613e-02 7.27552e-03 7.03096e-03
3.19672e-03 1.75527e-03 4.08169e-04 1.92427e-04 1.07047e-04
3.32798e-05 3.86419e-05 1.04112e-04 9.29740e-05 3.07590e-05
12r0.0
20r0.0
t
dose rate at specified locations
dose rate, mrem/hr
19**
  30.48 121.92 15.70
  91.44 121.92 15.70
152.40 121.92 15.70
213.36 121.92 15.70
274.32 121.92 15.70
  30.48 -121.92 15.70
  91.44 -121.92 15.70
152.40 -121.92 15.70
213.36 -121.92 15.70
274.32 -121.92 15.70
  30.48 321.92 15.70
  91.44 321.92 15.70
152.40 321.92 15.70
213.36 321.92 15.70
274.32 321.92 15.70
  30.48 -321.92 15.70
  91.44 -321.92 15.70
152.40 -321.92 15.70

```

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213.36	-321.92	15.70
274.32	-321.92	15.70
30.48	0.0	207.50
91.44	0.0	207.50
152.40	0.0	207.50
213.36	0.0	207.50
274.32	0.0	207.50
30.48	0.0	-34.89
91.44	0.0	-34.89
152.40	0.0	-34.89
213.36	0.0	-34.89
274.32	0.0	-34.89

20**

4.27e-01 3.86e-01 3.22e-01 2.94e-01 2.94e-01 2.98e-01 3.08e-01 2.94e-01
2.73e-01 2.60e-01 2.52e-01 2.50e-01 2.51e-01 2.51e-01 2.53e-01 2.55e-01
2.57e-01 2.61e-01 2.49e-01 2.32e-01 2.15e-01 1.95e-01 1.66e-01 1.29e-01
9.63e-02 6.10e-02 4.08e-02 2.73e-02 1.99e-02 1.67e-02 1.48e-02 1.37e-02
1.13e-02 7.98e-03 7.15e-03 7.31e-03 7.53e-03 7.90e-03 8.19e-03 8.52e-03
8.88e-03 9.12e-03 9.14e-03 9.00e-03 4.35e-03 4.03e-03 3.67e-03
1.03e-02 8.77e-03 7.75e-03 6.82e-03 6.21e-03 5.45e-03 4.67e-03 3.62e-03
2.97e-03 2.26e-03 1.83e-03 1.60e-03 1.44e-03 1.17e-03 7.19e-04 3.71e-04
2.66e-04 2.97e-04 8.27e-04 2.14e-03
t
end

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Input file *stldcablg* Exclusive Use. Calculation for photon dose in cab. Source in row 1

```

=morse
eu cab run photons low density case els 0.5 in steel
4f861e50
1$$ 0 1000 2500 200 1 0 1 0 0 0 0 0 0 0 e
2$$ 6 14 0 16 0 e
3$$ 0 20 0 0 0 0 0 4 2 20 0 0 0 0 0 78 0 0 3 e
4$$ -1 20 0 0 e
5$$ 2 0 0 0 0 1 34 4 4r0 1 2r0 1 1 f0 e
t
5320 nct conditions
0 0 1 0
rcc 1 0 0 2.14 0 0 27.150001 2.147
rcc 2 0 0 2.14 0 0 5.34 1.302
rcc 3 0 0 -2.52 0 0 4.660001 1.854
rcc 4 0 0 -0.07 0 0 2.21 0.997
rcc 5 0 0 7.48 0 0 4.92 1.302
rcc 6 0 0 29.29 0 0 2.21 0.997
rcc 7 0 0 29.29 0 0 4.66 1.854
rcc 8 0 0 -2.52 0 0 36.99 2.26
rcc 9 0 0 -3.71 0 0 38.760001 2.54
trc 10 0 0 32.76 0 0 2.290001 2.53999 4.287
rcc 11 0 0 35.73 0 0 2.06 0.955
rcc 12 0 0 38.27 0 0 0.25 3.135
rcc 13 0 0 35.05 0 0 4.83 4.287
rcc 14 0 0 -3.71 0 0 0.30 0.955
rcc 15 0 0 -7.52 0 0 37.12 2.625
rcc 16 0 0 29.60 0 0 15.10 5.12
rcc 17 0 0 -17.04 0 0 46.03 2.987
rcc 18 0 0 28.99 0 0 16.32 5.715
rcc 19 0 0 33.12 0 0 5.23 11.43
rcc 20 0 0 -17.04 0 0 2.84 0.955
rcc 21 0 0 42.60 0 0 3.81 1.590
rcc 22 0 0 44.68 0 0 1.73 1.270
rcc 23 0 0 43.57 0 0 1.11 0.715
rcc 24 0 0 -17.43 0 0 45.72 3.035
rcc 25 0 0 28.29 0 0 4.83 7.79
rcc 26 0 0 33.12 0 0 16.19 16.19
sph 27 0 0 49.31 16.19
rcc 28 0 0 -17.43 0 0 44.77 3.65
rcc 29 0 0 27.34 0 0 5.78 8.41
rcc 30 0 0 32.17 0 0 0.95 20.64
rcc 31 0 0 -17.43 0 0 49.60 16.19
rcc 32 0 0 -16.47 0 0 43.81 15.29
rcc 33 0 0 27.34 0 0 4.83 15.29
rpp 34 -22.86 22.86 -25.40 25.40 -18.38 -17.43
rpp 35 -30.48 30.48 -25.4 25.4 -18.38 65.5
sph 36 3r0. 1e12
rcc 37 0 0 12.4 0 0 6.64 1.302
rcc 38 0 0 19.04 0 0 4.92 1.302
rcc 39 0 0 23.96 0 0 5.33 1.302
rpp 40 -30.48 30.48 -8.89 8.89 -18.38 65.5
rpp 41 -30.48 30.48 -20.955 20.955 -18.38 65.5
rpp 42 -304.799999999 304.799999999
-089.534999999 89.534999999
-018.379999999 65.499999999
rpp 43 -2000. 2000. -2000.0 2000.0 -177.765 1000.000
rpp 44 -2000. 2000. -2000.0 2000.0 -185.385 -177.765
rpp 45 -2100. 2100. -2100.0 2100.0 -200. 1200.
rpp 46 -306.07 306.07 -90.804 90.804 -19.65 66.77
end
stl +1 -2 -5 -37 -38 -39
src +37
air +5 or +4 or +2 or +38 or +39 or +6
air +8 -1 -3 -7 or +11 or +12 or +14 or +15 -9 -10 or +16 -10 -13 -21
-9 or +20 or +22 or +23 or +24 -17 or +25 -17 -18 or +26 -18
-19 -21 or +27 -26 -18 -19 -21
air +35 -34 -31 -30 -26 -27
stl +3 -4
stl +7 -6
stl +9 -8 -14
stl +10 -9 or +13 -11 -12

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```

stl    +17 -15 -20
stl    +18 -16 -21 -15 or +21 -22 -23
stl    +19 -18
alm    +28 -24
alm    +29 -24 -25 -17 -18 or +30 -29
alm    +31 -32 -33
wep    +32 -28
wep    +33 -29
stl    +34
un2    +36 -35
un1    +40
un1    +36 -40
un3    +41
un3    +36 -41
trl    +42
con    +44
air    +43 -46
voi    +36 -45
ext    +45 -43 -44
stl    +46 -42
end
1 2 5 5 16 3 4 5 6 7 8 9 10 11 12 13 14 5 15 5 15 5 15 5 16 5 15 15 5
18r1 1 2 2 3 3 0 0 0 0 0 0
1 3 2 2 2 7r1 3r4 2r5 1 -1000 2 -1000 2 -1000 -1 6 2 0 1000 1
10 5 1 0 0
10r2 10r1 10r3 10r1 10r2
0 1 1
6** 1000. 0. 4.8186E+09 0. 29.178 31.782 -47.657 -45.053 -0.07 31.51
12$$ 1 2 5r3 4 5r5 6
13$$ 99005
99002
8016 92235 92238 94239 94240
13027
6012 1001 8016 5010 11023
99003
14** 1.0
1.0
1.1405e-2 2.5197e-5 2.861e-4 2.5022e-3 2.8618e-3
6.026e-2
2.3349e-2 6.1477e-2 2.4113e-2 1.7444e-4 2.8229e-4
1.0
17**
0.00000e+00 0.00000e+00 0.00000e+00 1.30861e-10 3.92057e-10
1.17454e-09 3.53699e-09 3.92799e-06 2.67688e-07 4.89375e-07
3.68941e-06 5.87752e-06 2.91768e-07 1.39174e-05 7.24945e-05
1.17885e-04 4Z
t
dose rate at specified locations
dose rate, mrem/hr
19**
589.28 0.0 15.7
-589.28 0.0 15.7
20**
1.03e-02 8.77e-03 7.75e-03 6.82e-03 6.21e-03 5.45e-03 4.67e-03 3.62e-03
2.97e-03 2.26e-03 1.83e-03 1.60e-03 1.44e-03 1.17e-03 7.19e-04 3.71e-04
2.66e-04 2.97e-04 8.27e-04 2.14e-03
t
end

```