ENERGY*SOLUTIONS*

2 December 2010
E&L-108-10

Mr. Pierre Saverot
Licensing Branch
Division of Spent Fuel Storage and Transportation
Office of Nuclear Material Safety and Safeguards
U.S. Nuclear Regulatory Commission
Washington, DC 20555

SUBJECT:	Response to RAI dated October 26, 2010
Re:	Request for Amendment of US Nuclear Regulatory Commission Certificate of Compliance No. 9204 for the Model 10-160B Shipping Cask, E&L-037-10, 2 April, 2010
Docket No.	71-9204
TAC No.	L24435

Dear Mr. Saverot:

Enclosed is our response to the Request for Additional Information (RAI) related to our 10-160B submittal. In addition to specific responses to the RAI items, Energy*Solutions* provides additional revisions (Revision 3) to Chapters 1, 5, and 7 of the SAR incorporating the information provided in our response. Please replace the previously submitted Chapters 1, 5 and 7 with the ones attached to this letter. Additionally, the Revision Control Sheet has been updated to document the current revision level of the various sections of the SAR and the SAR cover page has been revised. The attachments provided are:

1) Response to RAI #2

2) Chapter 1 – The limitation on activity by A_2 has been removed from Section 1.2.3.1, the specification of waste form has been removed from Section 1.2.3.1 as it is specified in Section 1.2.3.2, and the reference to the calculation in Chapter 5 has been revised.

3) Chapter 5 – A revision to the calculation of gamma activity limits has been made.

4) Chapter 7 – The procedure for use of the gamma activity limits has been revised.

5) Revision Control Sheet has been revised.

6) The SAR cover page has been revised

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Should you or members of your staff have any additional questions about the request, please contact Mark Whittaker at (803) 758-1898.

Sincerely,

Mirza I. Baig
Technical Services Manager – Engineering & Licensing

Attachments:

1) RSI Responses
2) SAR Chapter 1
3) SAR Chapter 5
4) SAR Chapter 7
5) SAR Revision Control Sheet
6) SAR Cover Page

RAI 5-1

Demonstrate it is appropriate to reduce the SAS4 calculated dose rates by a factor of two for the 10-160B package shielding analysis

In its response to RAI 5-1, the applicant states: "In fact, the validation report for SAS4 (NUREG/CR-6484) states that 'gamma-ray dose-rate calculations with major contributions due to active fuel show over a factor of 2 overprediction of the measured quantities.'" The staff reviewed, in particular, Chapter 4 of NUREG/CR-6484, which shows that SAS4 does not always overpredict the dose rates by a factor of two. The staff's review of the validation cases presented in NUREG/CR-6484 indicates that SAS4 actually underestimates dose rates for simple geometries as presented in Table 28. In fact, Table 28 indicates that the SAS4 model predicts dose rates fairly accurately for well-defined gamma and neutron sources; most results show underestimates are within 6 to 8 percent accuracy. Table 28 also shows that the thicker the shielding, the bigger the underestimate is for up to a 25 cm iron slab. Even in Table 29, there is a case (i.e., VSC (58.2)) that shows that SAS4 underestimated the dose rate by a factor of almost three.

In addition, review of NUREG/CR-6484 indicates that the statement quoted by the applicant is for a special case of a spent fuel cask. The large errors in the calculated dose rates presented in Section 4 of NUREG/CR-6484 appear to be related to spent fuel section of the casks. As such, the large errors in the dose rates may have been introduced by a variety of factors, including propagations of errors in the source term calculations of the spent fuels, inaccuracy in the fuel depletion data, simplifications of the geometry in the fuel depletion model, errors in the cross section data, and errors in cask modeling. In fact, as stated in NUREG/CR-6484, the developer was not quite sure what the causes of the errors were. It is the staff's position that these errors are not representative of the errors likely for the 10-160B package.

The staff also reviewed the SAS4 manual. The SAS4 manual states: "The primary function of the Shielding Analysis Sequence No. 4 (SAS4) control module is to perform a three-dimensional (3-D) Monte Carlo shielding analysis of a **nuclear fuel transport or storage cask** using an automated biasing procedure." The primary targeted application of the SAS4 is for spent fuel storage and transportation package shielding calculations. As such, the fact that SAS4 overpredicts dose rates for some casks cannot be used as a basis for adjusting the results by a factor of two. The fact that the large errors in the calculated dose rates presented in Section 4 of NUREG/CR-6484 appear to be related to spent fuel in the casks show that these results may not be applicable to the 10-160B cask. The applicant needs to either demonstrate that decreasing the calculated dose rates by a factor of two in the revised SAR is appropriate or revise the graphs for Maximum Activity for Point and Unit Density Distributed Sources in the revised SAR. Benchmarks of the SAS4 to the 10-160B cask dose rate measurements might be an acceptable approach for validating the code for the 10-160B packaging design.

In addition, reducing the calculated dose rates by a factor of two causes a self-inconsistency in SAR. The staff used 13.4 Ci of Co-60 as a sample problem to check how this methodology works. The results seem to indicate that the data found from these curves produced 200% of the allowable content.

Based on the information provided in page 5-2 of the SAR and the examples in Attachment 1 of the SAR, the maximum allowable Co-60 source is 13.4 Ci. Since Co-60 gives two photons,1.17 MeV and 1.33 MeV, per decay, the total number of photons from the 13.4 Ci source is 4.96×10^{11} ($13.4 \times 3.7 \times 10^{10}$) for each energy group. From the curve in Attachment 1 of the SAR, the corresponding maximum radiations from these two gammas are 2.98×10^{12} γ/s and 1.7×10^{12} γ/s, respectively. Thus, the fractions of the 13.4 Ci of Co-60 for the two photons in these two energy group are:

$4.96 \times 10^{11}/(2.98 \times 10^{12}) = 0.166$, and

$4.96 \times 10^{11}/(1.7 \times 10^{12}) = 0.292$, respectively.

The total fractional radiation source is 0.458. From page 5-2, it is understood that 13.4 Ci of Co-60 is the source loading limit for the packaging design; based on the description of the methodology, the fraction of the total source load should be very close to 1.0 rather than 0.458. Therefore, using the methodology and the curves in Chapter 7 to determine the maximum Co-60 source that can be shipped will exceed the design basis source described in Section 5.2.2 of the SAR.

This information is needed for the staff to determine the 10-160B packages meet the regulatory requirements of 10 CFR 71.47 and 71.51.

RESPONSE:
The factor of two (2) correction factor has been removed from the calculation and the gamma dose limit curves adjusted accordingly. This change has been incorporated in the revised Chapter 5 and Chapter 7 which are included with this submittal.

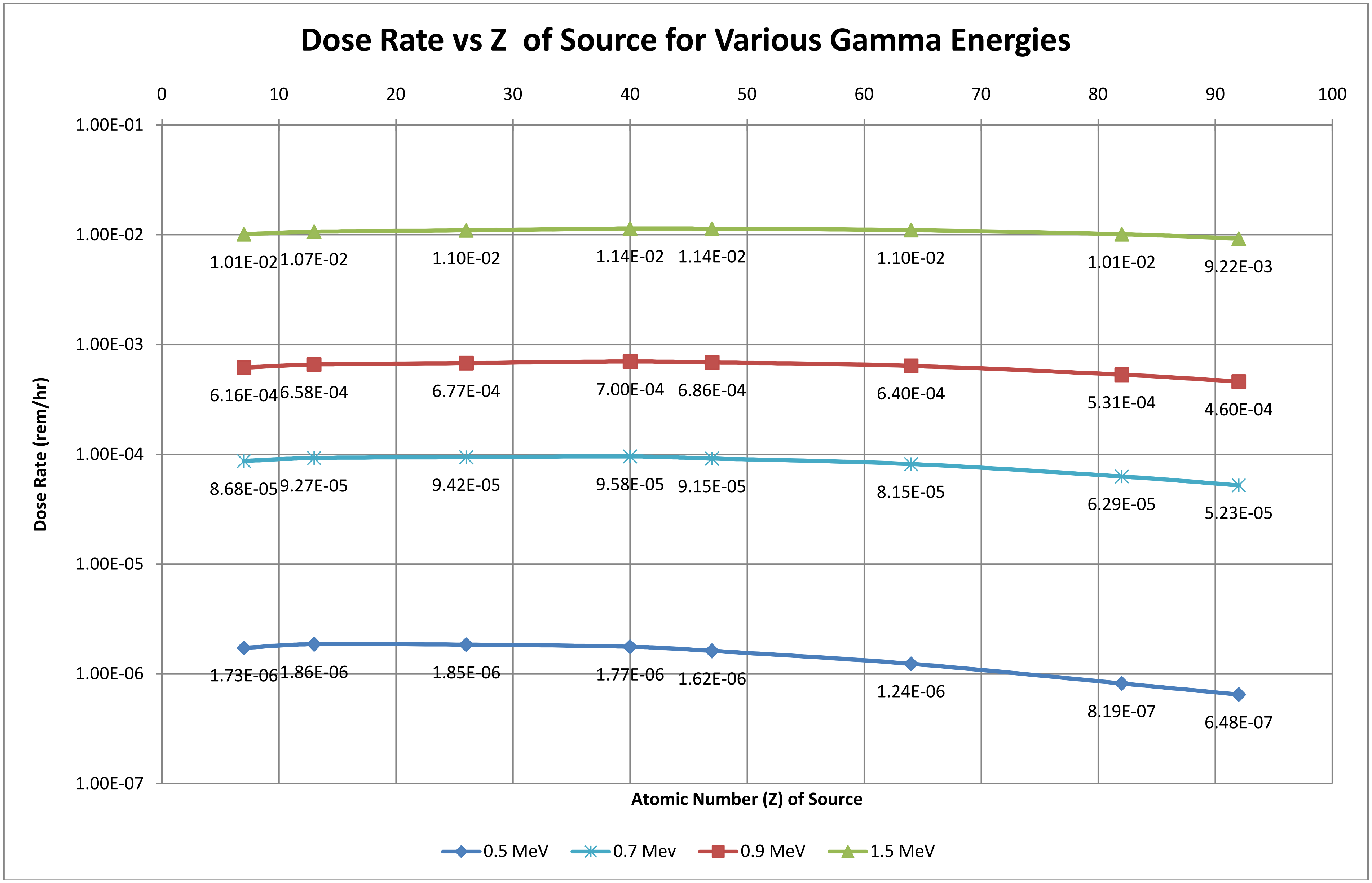
RAI 5-2

Demonstrate that using z=40 as the material of the content produces conservative results for gamma sources in all energy range

Section 5.5 of the SAR states: "The material of the source was selected as Zr (z=40); multiple calculations with various materials showed a material selection of Zr was conservative." Provide the information used to determine that z=40 is the most conservative content for the dose calculations. Be sure to include what energy range of the photons was used in this study for gamma radiation and explain why this result is appropriate for gammas in both high and low energy ranges because the gamma attenuation through materials is highly dependent on the energy of the particles.

This information is needed for the staff to determine the 10-160B packages meet the regulatory requirements of 10 CFR 71.47 and 71.51.

RESPONSE:
Contact dose rates were calculated for a distributed source that fills the cask cavity and is at the cask content weight limit, i.e., r=86cm, h=194cm and ρ=1.46 g/c. The composition of the source was varied over a range of materials with different atomic numbers (Z values) from 7 to 92. The gamma energy was varied from 0.5 MeV to 1.5 MeV. The dose rates at each energy are plotted versus the Z of the material. The plot shows a Z=40 (zirconium) is conservative, i.e., gives a larger dose rate for all energies except for 0.5 MeV. Since gammas of 0.5 MeV and less do not contribute significantly to the cask external dose rates, the use of a Z=40 for the source is appropriate.


Dose Rate vs Z of Source for Various Gamma Energies
0
10
20
30
40
50
60
70
80
90
100
1.00E-01
1.00E-02
1.00E-03
1.00E-04
1.00E-05
1.00E-06
1.00E-07
Dose Rate (rem/hr)
1.01E-02
1.07E-02
1.10E-02
1.14E-02
1.14E-02
1.10E-02
1.01E-02
9.22E-03
6.16E-04
6.58E-04
6.77E-04
7.00E-04
6.86E-04
6.40E-04
5.31E-04
4.60E-04
8.68E-05
9.27E-05
9.42E-05
9.58E-05
9.15E-05
8.15E-05
6.29E-05
5.23E-05
1.73E-06
1.86E-06
1.85E-06
1.77E-06
1.62E-06
1.24E-06
8.19E-07
6.48E-07
Atomic Number (Z) of Source
0.5 MeV
0.7 Mev
0.9 MeV
1.5 MeV

RAI 5-3

Justify the use of the Density Correction Factor (DCF) for gammas with energy other than 0.9 MeV.

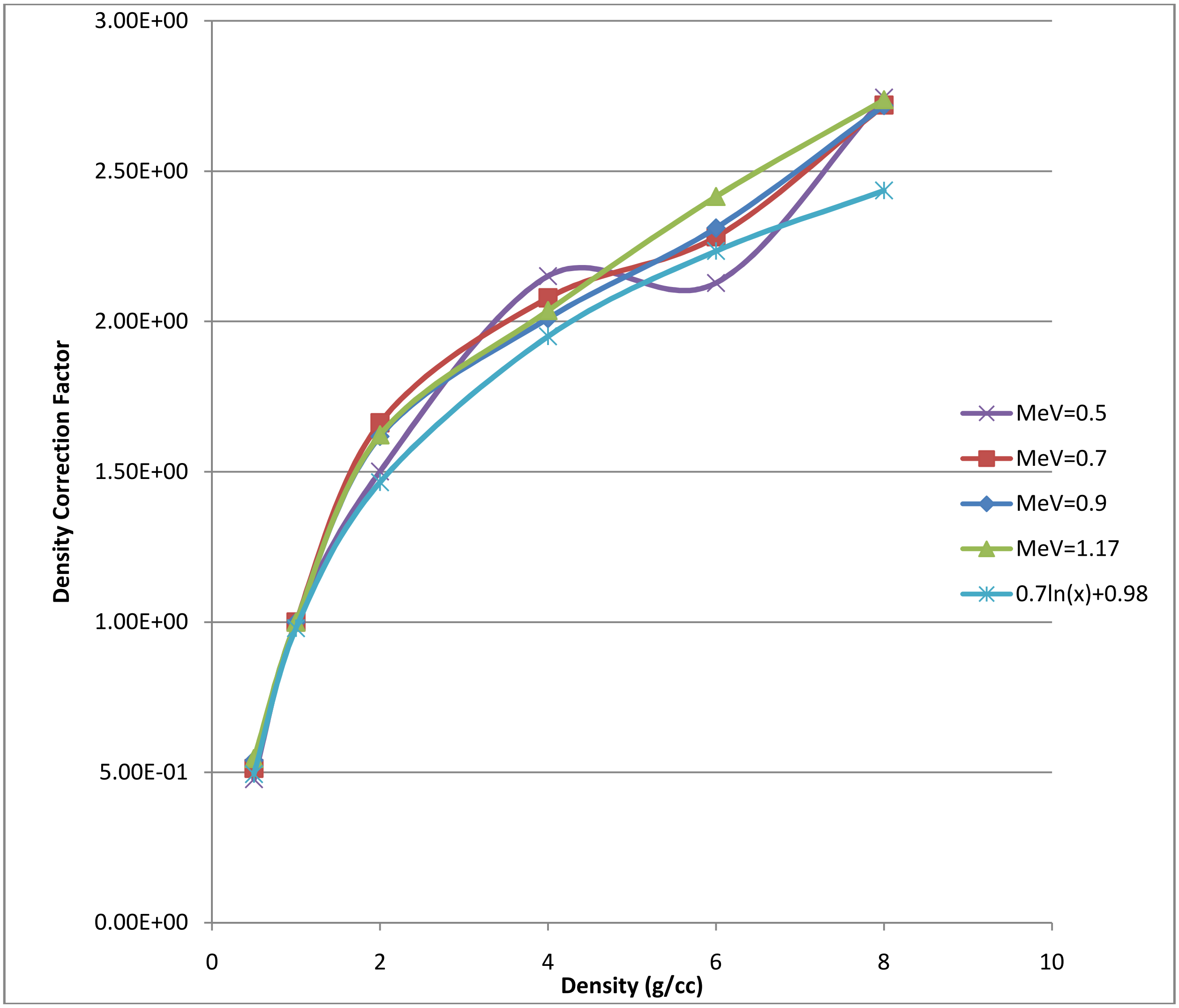
The equation for the DCF was determined using 0.9 MeV gammas. The staff believes that gammas of higher or lower energy would have different attenuation through varying density material. A higher percentage of lower energy gammas would tend to be stopped than the higher energy gammas. Therefore the staff does not find that the DCF equation would necessarily be applicable or bounding for gammas of other energy. Justify that this equation is applicable or bounding for gammas of all energies that are to be stored in the 10-160B.

The SAR also states that the geometry was changed when performing these density studies. Provide additional information on how exactly the geometry has been changed.

This information is needed to determine that the 10-160B package meets the requirements of 10 CFR 71.47 and 71.51.

RESPONSE:
Additional SCALE calculations were performed over a range of energies to determine the applicability of the DCF equation at different energies. A plot of these results is shown below. To incorporate the results at the range of energies, a new equation was fitted to the data and then adjusted to give conservative results except over a small density range for energies of 0.5 MeV. The equation of the adjusted fitted line is shown on the plot, DCF=0.7ln(x)+.98. Since most distributed sources transported in the 10-160B will have a bulk density less than 4 and energies over 0.5, the small range of non-conservative values is not significant. The equation of the adjusted fitted line will replace the equation previously provided as the DCF.

As stated in Section 5.5 for the configuration of the distributed source, the geometry is adjusted with the density of the material such that "H=2r (approximately the geometry of the cask cavity) and Vρ=14,500 lbs (maximum allowed weight of contents)", with the constraint that the source cannot exceed the cavity size. This configuration specification is used in the determination of the DCF, i.e., as the density increases the volume of the source is reduced.



RAI 7-1

Revise the 3rd paragraph of page 7-1 to make the maximum activity as the dominating restriction of the package content

On page 7-1 of the revised SAR, the applicant states: "The maximum permissible activity is 3000 A_2 or the maximum activity in gammas/sec, determined per Attachment 1, whichever is less." Since the maximum activity is the primary control for the payload, the applicant is requested to revise the operating procedures to clearly indicate content limit is controlled by the quantity of radioactive materials. The use of A_2 as the restriction to the quantity of the contents was intended for LSA packages based on the regulations prior to 2004.

The applicant is requested to provide this information. This information is needed for the staff to determine the 10-160B packages meet the regulatory requirements of 10 CFR 71.47 and 71.51.

RESPONSE:
It was our understanding that Regulatory Guide 7.11 established maximum activity limits, in units of A_2, for Category 1, 2, 3 containers used for transport of radioactive material. However, with your explanation that the limits of Regulatory Guide 7.11 do not apply, we have removed the 3000 A_2 limitation in the contents and operating procedures. The revised Chapters 1 and 7 are included in our submittal.

RAI 7-2

Add a procedure to measure and determine the TI (Transport Index) in the step prior to shipment measurement

Chapter 7 of the revised SAR describes the operating procedures for 1-160B package. However, the measurement and calculation of the TI requirements were not presented in the operating procedures.

The applicant is requested to modify the SAR to add this important task in the operating procedure. This information is needed for the staff to determine the 10-160B packages meet the regulatory requirements of 10 CFR 71.47.

RESPONSE:
As stated at the beginning of Chapter 5, the 10-160B will be operated under "exclusive use" and the provisions of 10 CFR 71.47(b) apply. Thus the TI is not applicable to 10-160B shipments and measurements and calculations of the TI are not needed in the operating procedures.

RAI 7-3

Provide a limit for maximum energy and percentage of emissions.

Step 4 in Attachment 1 to Chapter 7 currently states that any photons with energies above 2.5 MeV should be placed in the highest energy group (2.0-2.5MeV). The staff understands that this is intended to cover certain nuclides that may have a very low percentage high energy gamma emission. However the current analyses and CoC, if approved as is, do not prohibit an entire source of high energy gammas (above 2.5 MeV) to be shipped. Therefore the staff requests that the applicant create an upper limit of either energy, or percentage of emissions, or some combination of both that would be reasonably bounded by the analysis. The applicant should justify their limit.

This information is needed to determine that the 10-160B package meets the requirements of 10 CFR 71.47 and 71.51.

RESPONSE:
Additional SCALE calculations were performed for energy ranges up to 4 MeV. The maximum activity curves were revised to include these results and Chapters 5 and 7 were revised to provide for gamma energies not greater than 4 MeV. Radionuclides producing gamma energies above 4 MeV will be prohibited.

RAI 7-4

Revise the methodology for Step 5 in Attachment 1 to Chapter 7 of the revised SAR to use the maximum energy instead of the mid-point energy of each photon energy group.

Using the mid-point for each photon energy group may substantially underestimate the actual dose rate, especially for the high photon energy groups. For example, the delta E (from mid-point to upper limit) is 0.25 MeV for the energy group of 2.0 – 2.5 MeV which is greater than the total energy ranges of the typical energy groups (as stated for Step 4 in Attachment 1) of 0.3-0.4, 0.4-0.6, 0.6-0.8, and 0.8-1.0 MeV. The staff believes that neglecting such a large energy range for the higher photon energy groups may lead to reduced conservatism in the dose rate calculations.

This information is needed to determine that the 10-160B package meets the requirements of 10 CFR 71.47 and 71.51.

RESPONSE:
The purpose of the maximum activity calculation is to ensure the requirements of 10 CFR 71.47 are met. Regardless of the maximum activity calculation result, the shipper of the cask is required to measure the external dose rates prior to transport to demonstrate the dose rates of 10 CFR 71.47 are met. Most shippers apply an additional conservatism by setting the dose limit for release at 20-30% below the limit, e.g., 7-8 mrem/hr at 2m. Energy*Solutions* believes the demonstration by measurement is sufficiently conservative and no additional conservatism in the calculation of the maximum activity is necessary.

RAI 7-5

Revise the methodology for Step 6 in Attachment 1 to Chapter 7 of the revised SAR to explain how the Density Correction Factor (DCF) will be calculated in the source density is less than 1 or greater than 8 g/cc..

The equation for DCF used in Step 6 is based on a curve fit for calculations performed in Table 5.8 for the DCF as a function of the source density. However, the minimum and maximum density used in these calculations was 1 and 8 g/cc, respectively. Explain how DCF will be used in this methodology for source densities less than 1 and greater than 8 g/cc.

This information is needed to determine that the 10-160B package meets the requirements of 10 CFR 71.47 and 71.51.

RESPONSE:
The revised DCF curve, discussed in response 5-3, extends to density of 0.5 g/cc. Examination of the curves provided in response 5-3 indicates that the DCF curve matches the shape of plotted density calculation results and is especially conservative at 8 g/cc. It is appropriate to use the equation for densities both above and below the density values plotted.

CONSOLIDATED SAFETY ANALYSIS REPORT

FOR

MODEL 10-160B

TYPE B RADWASTE SHIPPING CASK

REVISION 3

December 2010

Energy*Solutions*
140 STONERIDGE DRIVE
COLUMBIA, SOUTH CAROLINA 29210

REVISION CONTROL SHEET

TITLE: Consolidated Safety
Analysis Report for 10-160B
Shipping Cask

AFFECTED PAGE(S)	DOC. REV.	HEADER DATE	REMARKS
Entire Document	0	December 2007	Consolidate Revision 0 Incorporates all previous changes to the SAR
Cover Page i 1-1 – 1-6 5-1 – 5-15 7-1 – 7-9	1 “ “ “ “	April 2010 “ “ “ “	A vertical line in the margin indicates changed text. The date in the page header reflects the date of the change. The revision status of a particular page is noted by the revision number and header date.
Cover Page i 1-1 – 1-6 5-1 – 5-18 7-1 – 7-12	2 “ “ “ “	September 2010 “ “ “ “	A vertical line in the margin indicates changed text. The date in the page header reflects the date of the change. The revision status of a particular page is noted by the revision number and header date.
Cover Page i 1-1 – 1-6 5-1 – 5-18 7-1 – 7-12	3 “ “ “ “	December 2010 “ “ “ “	A vertical line in the margin indicates changed text. The date in the page header reflects the date of the change. The revision status of a particular page is noted by the revision number and header date.

1.0 GENERAL INFORMATION

1.1 Introduction

This Safety Analysis Report describes a reusable shipping package designed to protect radioactive material from both normal conditions of transport and hypothetical accident conditions as required by 10CFR71. The package is designated the Model 10-160B package.

1.2 Package Description

1.2.1 Packaging

The package consists of a steel and lead cylindrical shipping cask with a pair of cylindrical foam-filled impact limiters installed on each end. The package configuration is shown in Figure 1-1. Cask assembly drawings are included in Section 1.3. The internal cavity dimensions are 68 inches in diameter and 77 inches high. The cylindrical cask body is comprised of a 2 inch thick external steel shell and a 1 1/8 inch internal steel shell. The annular space between the shells is filled with 1 7/8 inch thickness of lead. The base of the cask consists of a 5½ inch thickness of flat circular steel plates (2½ and 3 inches) which are welded together. The cask primary lid also consists of a 5½ inch thickness flat circular steel plates (2½ and 3 inches) which are welded together. The primary lid is fastened to the cask body with twenty-four, 1 3/4 - 8 UNC bolts. There is a secondary lid in the middle of the primary lid. This secondary lid is attached to the primary lid with twelve, 1 3/4 - 8I UNC bolts. A 12 gauge stainless steel liner (0.105 inches) welded to the cask cavity and lid surface protects all accessible areas from contamination. Also, a steel thermal shield is welded to the exterior barrel of the cask and serves as protection during the fire accident.

The impact limiters are 102 inches in the outside diameter and extend about 12 inches beyond the outside wall of the cask. There is a 47½ inch diameter void at each end. Each limited has an external shell, fabricated from stainless steel which cans the foam and allows it to withstand large plastic deformation without fracturing. The volume inside the shell is filled with a crushable, shock and thermal insulating polyurethane foam. The polyurethane is sprayed into the shell and allowed to expand until the void is completely filled. The foam bonds to the shell, which creates a unitized construction for the impact limiters. The upper and lower impact limiters are held together with eight circumferentially located ratchet binders which secure the limiters to the cask. A general arrangement drawing of the package is included in Appendix 1.3. It shows the package dimensions as well as all materials of construction.

1.2.1.1 Containment Vessel

The containment vessel is defined as the inner steel shell of the cask body together with closure features comprised of the lower surface of the cask lid and the primary and secondary lid bolts.

1.2.1.2 Neutron Absorbers

There are no materials used as neutron absorbers or moderators in the package.

1.2.1.3 Package Weight

Maximum gross weight for the package is 72,000 lbs. including a maximum payload weight of 14,500 lbs.

1.2.1.4 Receptacles

There are no receptacles on this package.

1.2.1.5 Vent, Drain, Test Ports and Pressure Relief Systems

Pressure test ports with manual venting features exist between the twin O-ring seals for both the primary and secondary lids. This facilitate leak testing the package in accordance with ANSI N14.5.

The drain and vent ports are provided with same venting features for venting pressures within the containment cavity, which may be generated during transport, prior to lid removal. Each port is sealed with an elastomer gasket. Specification information for all seals and gaskets is contained in Chapter 3.

1.2.1.6 Lifting Devices

Lifting devices are a structural part of the package. The General Arrangement Drawing in Appendix 1.3 shows two lifting lugs provided for removal and handling of the cask. Three lid lifting lugs are used for removal and handling of the secondary and primary lid. Refer to Section 2.4.3 for a detailed analysis of the structural integrity of the lifting devices.

1.2.1.7 Tie-downs

From the General Arrangement Drawing shown in Appendix 1.3, it can be seen that the tie-down arms are an integral part of the external cask shell. Consequently, tie-down arms are considered a structural part of the package. Refer to Section 2.4.4 for a detailed analysis of the structural integrity of the tie-down arms.

1.2.1.8 Heat Dissipation

There are no special devices used for the transfer or dissipation of heat.

1.2.1.9 Coolants

There are no coolants involved.

1.2.1.10 Protrusions

There are no outer or inner protrusions except for the tie-down arms described above.

1.2.1.11 Shielding

Cask walls provide a shield thickness of 1 7/8 inches of lead and 3 inches of steel. Cask ends provide a minimum of 5 inches of steel. The contents will be limited such that the radiological shielding provided (nominally 3¼ inches lead equivalent based on Co-60) will assure compliance with DOT and IAEA regulatory requirements.

An optional, removable steel insert may be installed inside the cask to provide additional shoring and shielding for the cask contents. The insert fits closely to the inside walls of the cask, but is not attached to the cask nor the contents. It may vary in thickness between ½ inch and

1½ inch on the sides, and is open on the top and bottom. It is approximately ½ inch shorter than the cask cavity.

1.2.2 Operational Features

Refer to the General Arrangement Drawing of the package in Appendix 1.3. There are no complex operational requirements associated with this package.

1.2.3 Contents of Packaging

1.2.3.1 Cask Contents

The contents of the cask will consist of:

1) Greater than Type A quantities of radioactive material in secondary containers.

2) That quantity of any radioactive material which does not generate spontaneously more than 200 thermal watts of radioactive decay heat.

3) The weight of the contents in the cask cavity will be limited to 14,500 lbs. If an insert is installed in the cavity, the maximum payload is reduced by the weight of the insert.

4) Transuranic Waste (TRU) with not more than 325 fissile gram equivalents (FGE) of fissile radioactive material.

5) The activity of gamma emitting radionuclides shall not exceed the limit discussed in Chapter 5 and determined per the procedure in Chapter 7 Attachment 1.

1.2.3.2 Waste Forms

The type and form of waste material will include:

1) By-product, source, or special nuclear material consisting of process solids or resins, either dewatered, solid, or solidified in secondary containers. (See Section 4.2.1 for specific limitations). Contents containing greater than 20 Ci of plutonium must be in solid form.

2) Neutron activated metals or metal oxides in solid form in secondary containers.

3) Miscellaneous radioactive solid waste materials, including special form materials and powdered solids in secondary containers. Powdered solids shipments shall be performed only when the most recent periodic leak test meets the requirements of Chapter 4, Section 4.9. Powdered solid radioactive material shall not include radioactive forms of combustible metal hydrides, combustible elemental metals, i.e., magnesium, titanium, sodium, potassium, lithium, zirconium, hafnium, calcium, zinc, plutonium, uranium, and thorium, or combustible non-metals, i.e., phosphorus.

4) TRU wastes are limited as described in Appendix 4.10.2, Transuranic (TRU) Waste Compliance Methodology for Hydrogen Gas Generation. TRU exceeding the fissile limits of 10 CFR 71.15 must not be machine compacted and must have no more than 1% by weight of special reflectors and no more than 25% by volume of hydrogenous material.

5) Explosives, corrosives, non-radioactive pyrophorics, and compressed gases are prohibited. Pyrophoric radionuclides may be present only in residual amounts less than 1 weight percent. The total amount of potentially volatile organic compounds present in the headspace of a secondary container is restricted to 500 parts per million.

10-160B GENERAL ARRANGEMENT

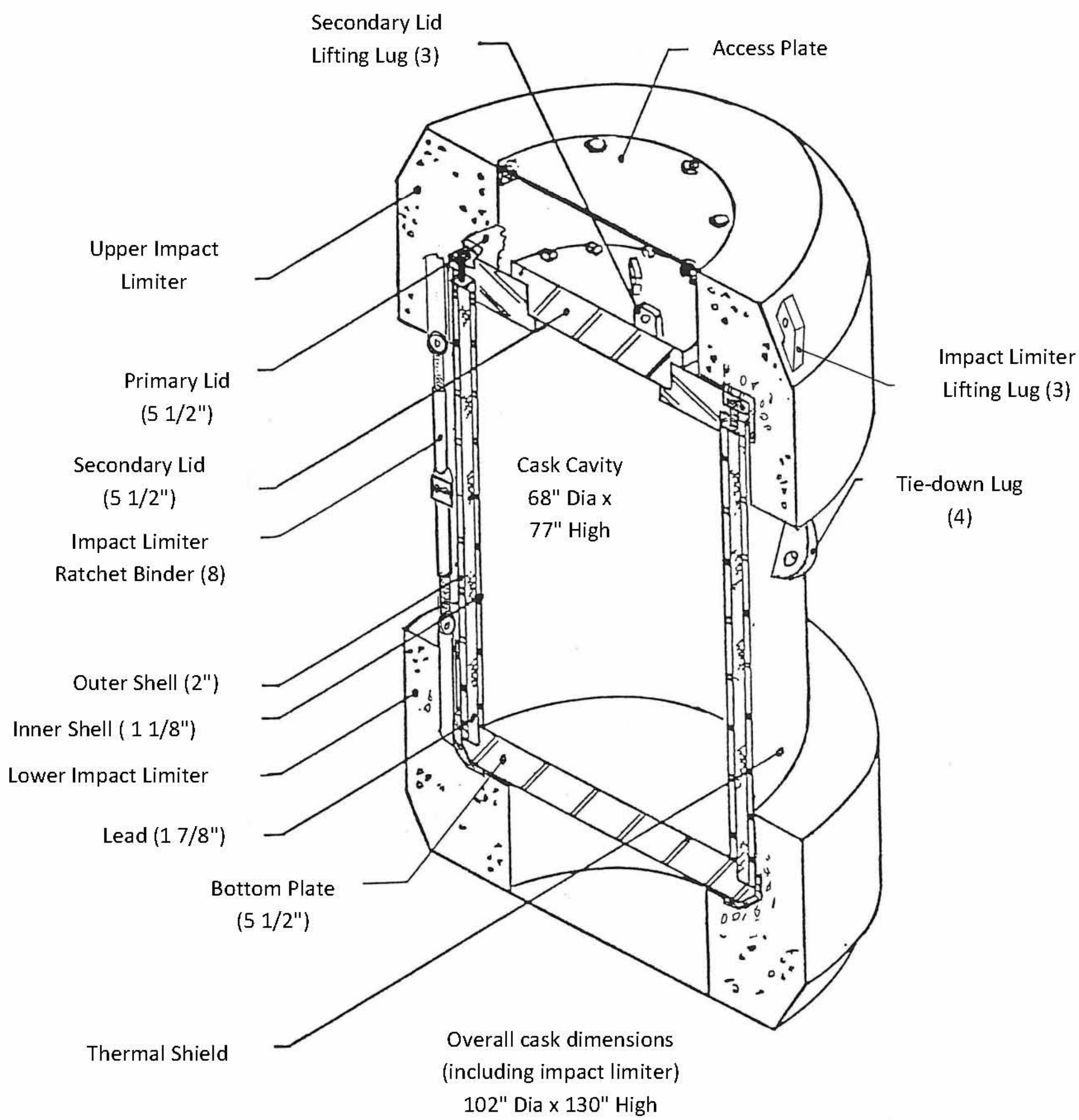


Figure 1-1

1.3 Appendix

10-160B Shipping Cask Drawing

(withheld as security-related sensitive information)

5. SHIELDING EVALUATION

5.1 Discussion and Results

5.1.1 Operating Design

The Model 10-160B packaging consists of a lead and steel containment vessel which 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 applicable regulations as determined in 10CFR71.47 (see Section 7.1, step 13c).

The 10-160B will be operated under "exclusive use" such that the contents in the cask will not create a dose rate exceeding 200 mrem/hr on the cask surface, or 10 mrem/hr at two meters from the outer lateral surfaces of the vehicle. The package shielding must be 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.

5.1.2 Shielding Design Features

The cask side wall consists of an outer 2-inch thick steel shell surrounding 1 7/8 inches of lead and an inner containment shell wall of 1 1/8-inch thick steel.

The primary cask lid consists of two steel layers with a total thickness of 5½ inches. The lid closure is made in a stepped configuration to eliminate radiation streaming at the lid/cask body interface.

A secondary lid is located at the center of the main lid, covering a 31-inch opening. The secondary lid is constructed of steel plates with a total thickness of 5½ inches with multiple steps machined in its periphery. These steps match those in the primary lid, eliminating radiation streaming pathways.

The cask bottom has an identical shielding effectiveness to the cask lids. It also consists of two layers of steel with a total thickness of 5 ½ inches.

Foam filled impact limiters cover the top and bottom of the vertically oriented cask. The impact limiters are conservatively ignored for the purpose of the shielding evaluation.

5.1.3 Maximum Dose Rate Calculations

Table 5.1 gives both Normal Conditions of Transport (NCT) and Hypothetical Accident Conditions (HAC) dose rates resulting from the maximum point sources (neutron and gamma) which may be in contact with either the side wall or the top (or bottom) of the cask. Maximum allowable dose rates given in 10CFR71 are shown in Table 5.1 for comparison. The following assumptions were used to develop the values shown in the table.

5.1.3.1 Normal Conditions

° The source is conservatively modeled as a point source centered in the cask cavity.

5.1.3.2 Accident Conditions

- ° The source is modeled as a point source on the inner liner adjacent to the location of the lead slump and in contact with the lid.

- ° Lead slump (see Section 2.7.1.1) considers the effect of loss of lead shielding from the slumped region in the side wall.

Table 5.1
Summary of Maximum Dose Rates (mrem/hr)

	Package Surface		1 m from Surface		2m from 8' trailer
Condition	Side	Top/Bottom	Side	Top/Bottom	Side
NCT					
Neutron Source	114	86.3	N.A	N.A.	9.44
Gamma Source	126	179	N.A	N.A.	9.96
Allowable	200	200	N.A.	N.A.	10.0
HAC					
Neutron Source	N.A.	N.A.	82.7	39.5	N.A.
Gamma Source	N.A.	N.A.	144	99.9	N.A
Allowable	N.A.	N.A.	1000.0	1000.0	N.A

5.2 Source Specification

5.2.1 Methodology

A unit point source is placed at the cask center. A neutron source and a gamma source are evaluated independently. The dose rate from the unit source is determined at the cask outer surface and at 2m from the 8' wide trailer. The ratio between the dose limit and the calculated value is determined. An equivalent source is set equal to the activity of the unit source times the smallest ratio of the surface limit to the calculated dose rate from the unit source. This equivalent source, which is the largest activity source that meets the cask NCT dose limits, is then used to evaluate the effects of the hypothetical accident. If the HAC limits are met for the maximum activity source, the cask complies with the requirements of 10 CFR 71. A mixed gamma and neutron source will also comply as the sum of the gamma and neutron dose rates must be less than the NCT dose limit and thus, as shown for the independently evaluated sources, the HAC limits will be met.

5.2.2 Gamma Source

SCALE models of the 10-160B cask are evaluated with a Co-60 source. The resulting equivalent source, approximately 13.4 Ci, gives a gamma dose rate of approximately 9.96 mrem/hr at 2m from the 8' wide trailer.

5.2.3 Neutron Source

SCALE models of the 10-160B cask are evaluated with a Pu-Be neutron source. A ^{239}Pu-Be source produces neutrons at a rate of approximately 1.4E+06 n/sec per Ci (Ref. 5.6.3). A 325 FGE (approximately 20 Ci) ^{239}Pu-Be source will produce approximately 2.8E+07 n/sec. The equivalent neutron source, which produces a dose rate of 9.4 mrem/hr at 2m from the 8' wide trailer, has an emission rate of 1.1 E+08 n/sec. Thus, the equivalent source used for the dose rate calculation is larger than the fissile gram limit imposed by the criticality evaluation of Chapter 6 and gives a conservative dose rate result. The neutron energy spectrum for a Pu-Be source is shown below.

Neutron Energy Spectrum for a Pu-Be Source (Ref. 5.6.3)

Energy Interval, E_i (MeV)	Fraction of neutrons in E_i
0-0.5	0.038
0.5-1	0.049
1-1.5	0.045
1.5-2	0.042
2-2.5	0.046
2.5-3	0.062
3-6.5	0.459
6.5-10.5	0.259
Total	1.000

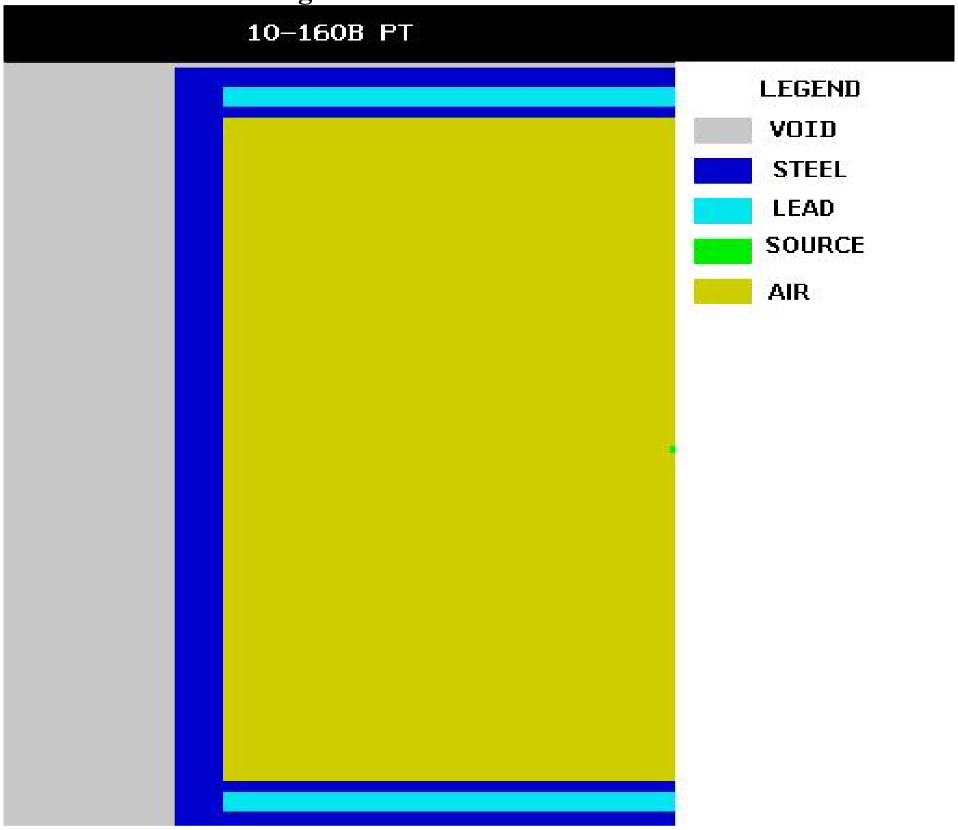
5.3 Model Specification

5.3.1 Description of Radial and Axial Shielding Configuration

Normal Conditions of Transport (NCT)

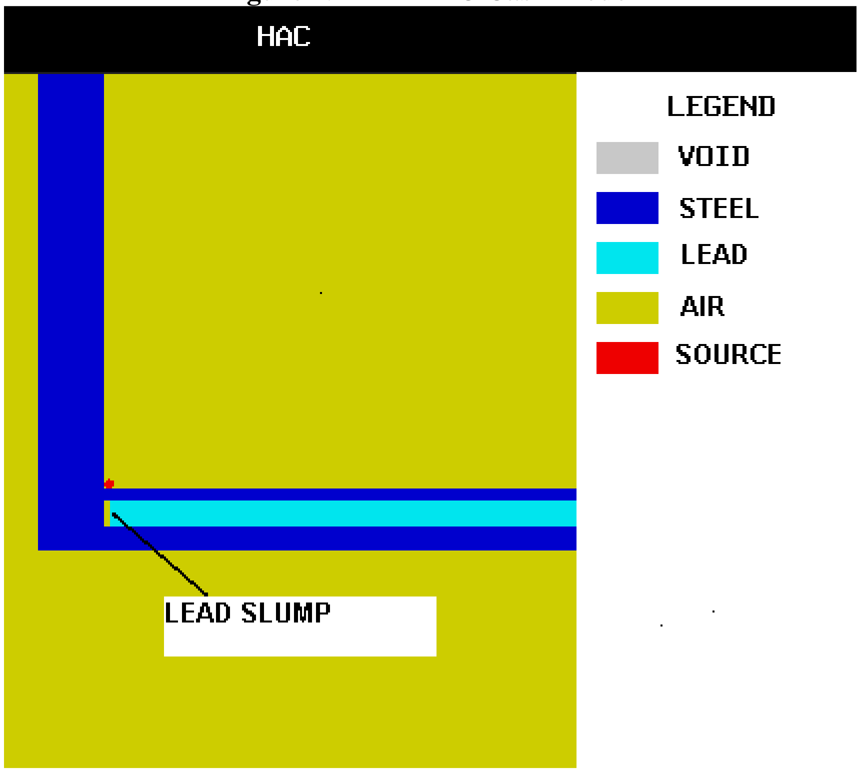
The walls of the 10-160B cask, 1.125" inner and 2" outer steel walls with a 1.875" lead layer between, are modeled as cylindrical shells around the cavity cylinder. The base and lid of the cask is a 5.5" steel plate. Impact limiters are conservatively ignored. This geometry is shown in Figure 5.1. In terms of shielding, the cask lid and bottom are the same so only one end is modeled. The cask is transported upright, i.e., with the axis of the cylinder vertical. Doses are evaluated at contact with the cask sidewall, with the cask lid, and at 2m from the 8' wide trailer.

Figure 5.1 NCT Cask Model



Hypothetical Accident Conditions (HAC)
As discussed in Section 2, the hypothetical accident conditions do not affect the geometry of the steel shells or the base or lid (see Section 5.3.1, above). The HAC model is shown in Figure 5.3. The lead slump resulting from the 30' drop (< 0.02") discussed in Section 2.7.1.1, is included in the HAC model as a void 0.05 cm high at the top of the lead shell. Doses are determined at 1 m from the sidewall and the lid.

Figure 5.2 HAC Cask Model



5.3.2 Material Properties

The properties of the cask materials are shown in Table 5.2

Table 5.2 Material Properties

Material	Composition	Density (g/cm^3)
Source	beryllium / cobalt	1.85 / 8.9
Cask inner wall	Steel	7.82
Cask outer wall	Steel	7.82
Cask shield layer	Lead	11.34

5.4. Shielding Evaluation

5.4.1. Methods

The gamma and neutron dose rates were calculated using SCALE, Module SAS4 (Ref.3), using the geometry described in Section 5.3. The dose locations are surface or point detectors at the cask surface or at 2m from the trailer for NCT and at 1m from the cask surface for HAC.

5.4.2. Input and Output Data

The SCALE input and output files are provided in 5.8. The input file lists the inputs that define the source dimensions, shield dimensions, materials and density, and source spectrum.

5.4.3. Flux-to-Dose-Rate Conversion

The flux to exposure rate conversion factors are listed in Table 5.3 and Table 5.4 (Ref. 5.6.2). These are the default conversion factors in SCALE.

Table 5.3 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
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

Table 5.4 Neutron Flux-To-Dose-Rate Conversion Factors And Mean Quality Factors ($\overline{QF}$)

Neutron Energy-E (MeV)	$\overline{QF}$*	$DF_n(E)$ (rem/hr) (n/cm^2-s)
2.5-08	2	3.67-06
1.0-07	2	3.67-06
1.0-06	2	4.46-06
10.-05	2	4.54-06
1.0-04	2	4.18-06
1.0-03	2	3.76-06
1.0-02	2.5	3.56-06
1.0-01	7.5	2.17-05
5.0-01	11	9.26-05
1.0	11	1.32-04
2.5	9	1.25-04
5.0	8	1.56-04
7.0	7	1.47-04
10.0	6.5	1.47-04
14.0	75	2.08-04
20.0	8	2.27-04

*Maximum value of QF in a 30-cm phantom.
#Read as 2.5 x 10^{-8}

5.4.4. External Radiation Levels

The SCALE model used to determine external radiation levels uses point or surface detectors to calculate the dose rates at various distances from the cask surface either radially or axially. The point detectors are aligned with the point sources, thus normally giving the maximum dose rates. The highest dose rate from the point or surface detectors is reported. Table 5.5 contains the maximum neutron and gamma dose rates found for each of the four cases, i.e., NCT radial, NCT axial, HAC radial, and HAC axial for each of the sources, neutron and gamma.

Table 5.5 Maximum External Radiation Levels

Normal Conditions of Transport	**Package Surface (mrem/h)**			**2 Meters from Trailer (mrem/h)**
Radiation	Top	Side	Bottom	Side
Neutron Source	86.3	114	86.3	9.44
Gamma Source	179	126	179	9.96
10 CFR 71.47 Limit[1]	200	200	200	10

1. shipped as "exclusive use"

Hypothetical Accident Conditions	**1 Meter from Package Surface mSv/h (mrem/h)**

Radiation	Top	Side	Bottom
Neutron Source	39.5	82.7	39.5
Gamma Source	99.9	143.6	99.9
10 CFR 71.51(a)(2) Limit	1000	1000	1000

5.5 Gamma Activity Limits

Using the cask model described in 5.3, additional calculations were performed to determine the maximum activity that can be contained in the 10-160B and meet the dose rate limits of 10 CFR 71.47. Since the results in Table 5.5 show that contents meeting NCT limits will meet HAC limits, maximum activity was determined only for NCT.

Two contents configurations were evaluated:

Point source – activity in a right circular cylinder; OD = 1 cm and height = 1 cm, centered in the cask cavity. The required secondary container is ignored for the shielding calculation.

Distributed source – activity homogeneously distributed in a right circular cylinder centered in the cask cavity with H=2r (approximately the geometry of the cask cavity) and Vρ=14,500 lbs (maximum allowed weight of contents); with a maximum r and H of 86cm and 194 cm, respectively (the cask cavity size is r=86.4cm and H=195.6cm). The required secondary container is ignored for the shielding calculation. Density (ρ) ranged from 0.5 to 8 g/cc. The material of the source was selected as Zr (z=40); multiple calculations with various materials showed a material selection of Zr was conservative.

Dose rates were calculated at 2m from the edge of the 8' wide cask trailer with a single energy group for each calculation varying from 0.3 to 4.0 MeV and an activity of $1x10^{12}$ gammas/sec. A surface detector was placed at 322cm from the centerline (x=322) extending from the midpoint (z=0) to 100 cm, divided into 10 segments. The maximum segment dose rate value was used. The flux to exposure rate conversion factors are the same as used previously and are listed in Table 5.4 (Ref. 5.6.2).

The maximum allowed gamma activity in gammas/sec for each gamma energy was determined by multiplying the modeled source activity ($1x10^{12}$ gammas/sec) by the ratio of the dose rate limit (10 mrem/hr) to the calculated dose rate. The distributed source results are for contents with a density of 1 g/cc (unit density). Results of the maximum activity calculations for the point source are given in Table 5.6

Table 5.6 Point Source Activity Limits

Gamma Energy Group Range (MeV)	Group Mid-Point Energy (MeV)	SAS4 result at 2m (Rem/hr)	Activity equivalent to 10 mrem/hr (γ/s)
0.3-0.4	0.35	3.99E-07	2.51E+16
0.4-0.6	0.5	8.94E-06	1.12E+15
0.6-0.8	0.7	2.52E-04	3.96E+13
0.8-1.0	0.9	1.58E-03	6.31E+12
1.0-1.33	1.17	7.03E-03	1.42E+12
1.33-1.66	1.5	1.88E-02	5.31E+11

1.66-2.0	1.83	3.47E-02	2.88E+11
2.0-2.5	2.25	5.95E-02	1.68E+11
2.5-3.0	2.75	8.50E-02	1.18E+11
3.0-4.0	3.5	1.11E-01	8.98E+10

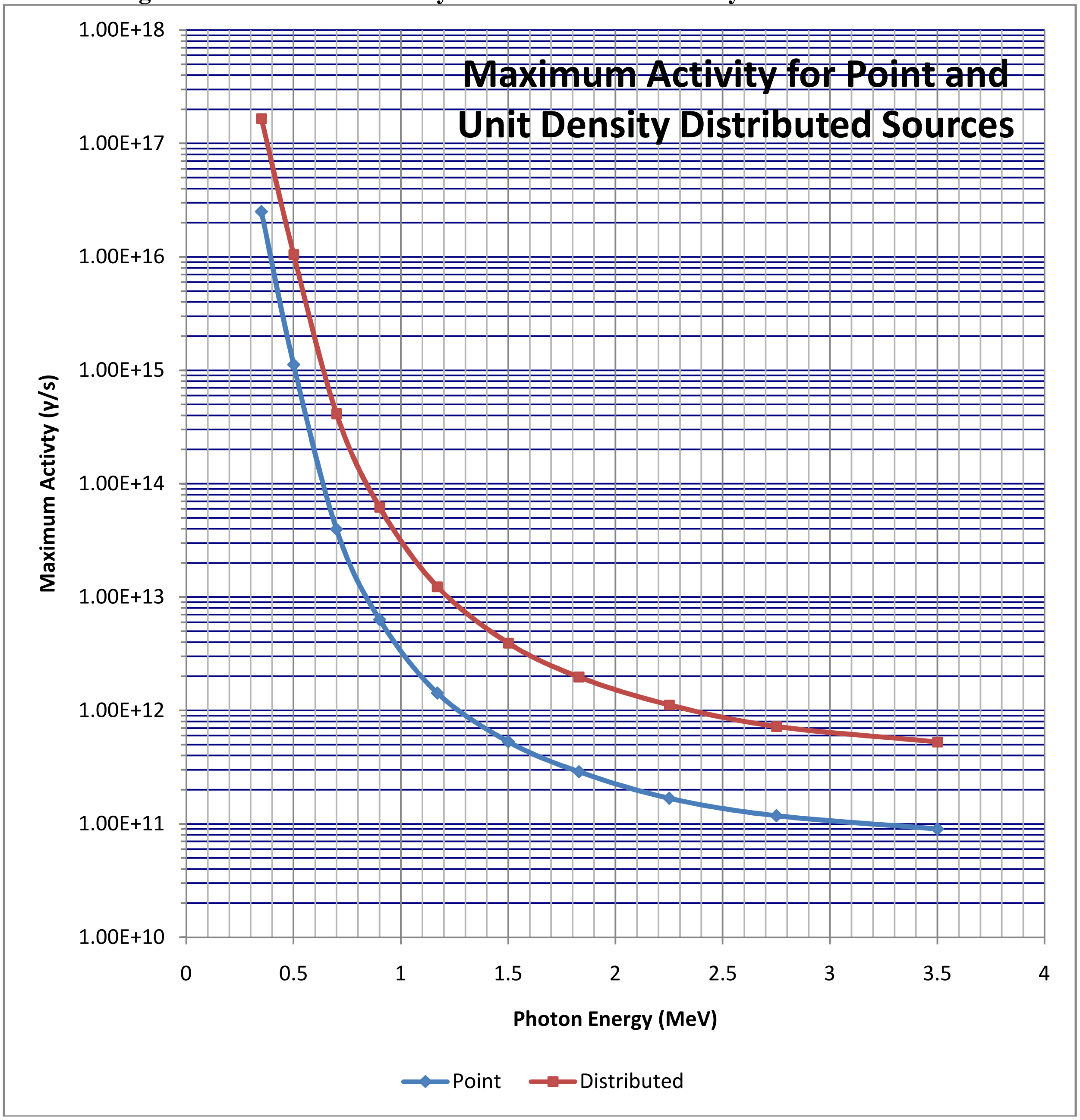
Results of the maximum activity calculations for the distributed unit density source are given in Table 5.7

Table 5.7 Distributed Unit Density Source Activity Limits

Gamma Energy Group Range (MeV)	Group Mid-Point Energy (MeV)	SAS4 result at 2m (Rem/hr)	Activity equivalent to 10 mrem/hr (γ/s)
0.3-0.4	0.35	6.03E-08	1.66E+17
0.4-0.6	0.5	9.50E-07	1.05E+16
0.6-0.8	0.7	2.43E-05	4.12E+14
0.8-1.0	0.9	1.62E-04	6.18E+13
1.0-1.33	1.17	8.10E-04	1.23E+13
1.33-1.66	1.5	2.55E-03	3.93E+12
1.66-2.0	1.83	5.08E-03	1.97E+12
2.0-2.5	2.25	8.93E-03	1.12E+12
2.5-3.0	2.75	1.39E-02	7.22E+11
3.0-4.0	3.5	1.89E-02	5.29E+11

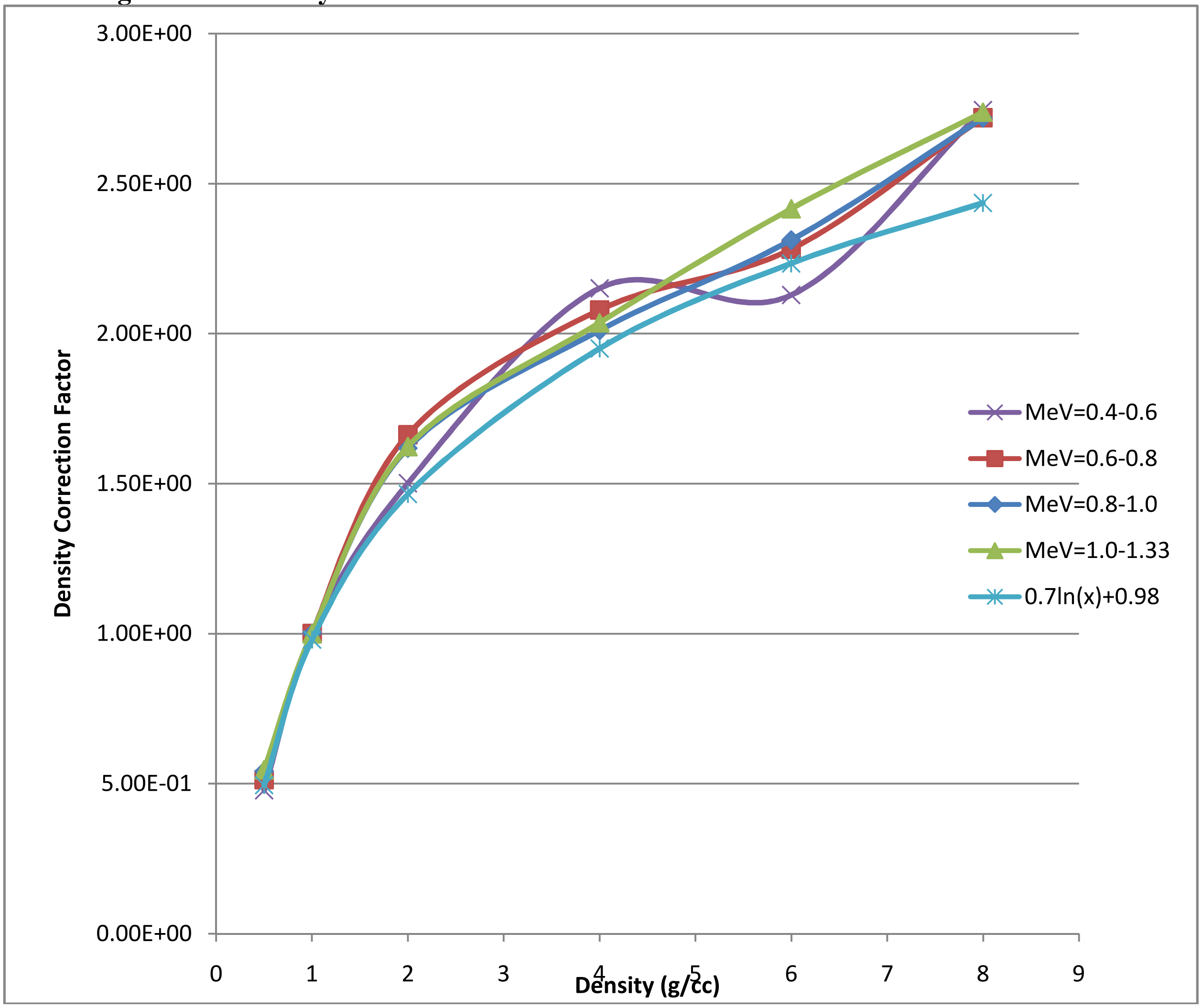
The cask activity limits for a point source and a unit density distributed source are plotted in Figure 5.3. The mid-point group energy values are used for plotting purposes.

Figure 5.3 Maximum Activity for Point and Unit Density Distributed Sources



Due to self absorption and geometry (radius and height change with density), the dose rates from distributed sources will change with density, decreasing as density increases, resulting in a maximum activity that increases with density. A correction factor for the actual source density is applied to the distributed unit source results to give the source specific gamma activity limit. Maximum activity results for gamma energies from 0.4 to 1.33 MeV with source density varying from 0.5 to 8 g/cc (with a corresponding change in source geometry) were used to determine the density correction factor (DCF). The DCF is the ratio of the maximum activity at a density other than 1 to the maximum activity for the unit activity source. The DCFs for each energy group were plotted versus density and a curve was conservatively fitted to the results. The equation of the curve is used to determine the DCF for any density of contents. Results of the density correction factor (DCF) calculations are plotted in Figure 5.4.

Figure 5.4 – Density Correction Factor



The equation for the fitted curve is:

$$DCF = 0.7\ln(\rho)+0.98$$

The maximum activity plot and the DCF, if applicable, are used to determine the maximum activity for any contents. A procedure for determining the maximum activity is provided in Chapter 7.

5.6 Conclusion

The cask shielding must be able to limit the dose rate to 1000 mrem/hr at 1 meter from any surface of the cask after the cask goes through the hypothetical accident. This section demonstrates compliance with this requirement. Structural analysis (Section 2.0) demonstrates that the cask wall will not fail during the hypothetical accident. However, lead slump may occur during a drop giving an isolated region in the sidewall without lead. Lead slump cannot occur in the lid or bottom of the cask since lead is not present in these parts of the cask. The dose rate at 1 meter from the cask in the slumped region (assuming a localized lead void) was determined to be less than the 1000 mrem/hr limit for a source at the NCT dose rate limit. With application of the gamma activity limits from Section 5.5, the contents will meet the dose rate limits.

5.7 References

5.7.1 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
5.7.2 ANSI/ANS 6.1.1-1977, "Neutron and Gamma-Ray Flux-to-Dose-Rate Factors."
5.7.3 Cember, H, *Introduction to Health Physics,* Pergamon Press, New York, 1987
5.7.4 Guide to Verification andValidation of the SCALE-4Radiation Shielding Software, NUREG/CR-6484, November 1996

5.8 SCALE Input Files for 10-160B Consolidated SAR Rev. 0

5.8.1 10-160b-pt-axial-HAC.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt axial
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=0 ity=2 izm=5 isn=8 irf=9504 ifs=1 mhw=5 frd=86.36 szf=1  end
 86.36 89.218 93.98 99.06 199.06   end
 4 1 2 1 4   end
xend
 ran=000000091807 tim=120 nst=1000 nmt=4000 nit=1000 nco=4 ist=0 ipr=0
 iso=0 nod=16 sfa=1e+12 igo=4 inb=0 ine=0 mfu=5 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 22 78 0 0 0 0 0 0 0 0 end
 det 199.06 0 76.79 199.06 0 81.79 199.06 0 86.79 199.06 0 91.79 199.06
 0 96.79 199.06 0 101.79 199.06 0 106.79 199.06 0 111.79 199.06 0
 116.79 199.06 0 121.79 199.06 0 126.79 199.06 0 131.79 199.06 0
 136.79 199.06 0 141.79 199.06 0 146.79 199.06 0 151.79 end
 sdl 99.06 199.06 299.06 399.06 end
 sdr 70 120 70 140 70 90 70 90 end
 sds 10 0 14 36 0 0 0 0 end
 sxy 5 84.36 86.36 -1 1 95.79 97.79 86.36 97.79 99.06 111.76   end
gend
10-160b pt hac
 0 0 0 0
 sph 85.36 0 96.79 1
 rcc 0 0 -97.79 0 0 195.58 86.36
 rcc 0 0 -98.79 0 0 197.58 89.218
 rcc 0 0 -97.79 0 0 195.53 93.98
 rcc 0 0 -111.76 0 0 223.52 99.06
 sph 0 0 0 300
 sph 0 0 0 500
 rcc 0 0 -97.79 0 0 195.58 93.98
 rcc 0 0 -211.76 0 0 423.52 199.06
  end
 src +1
 cav +2 -1
 inn +3 -2
 shd +4 -3
 our +5 -8
 inv +6 -9
 exv +7 -6
 slp +8 -3 -4
 det +9 -5
  end
 1 1 1 1 1 1 1 1 1
 0 0 0 0 0 0 0 0 0
 5 4 1 2 1 1000 0 4 4
 0
```

```
end
```

5.8.2 10-160b-pt-axial-igo0.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=1 ity=2 izm=3 isn=8 irf=9504 ifs=1 mhw=4 frd=1 szf=1  end
 1 97.79 111.76   end
 5 4 1   end
xend
 ran=000000111507 tim=120 nst=1000 nmt=4000 nit=1500 nco=4 ist=0 ipr=0
 iso=0 nod=0 sfa=1e+12 igo=0 inb=0 ine=0 mfu=5 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 22 78 0 0 0 0 0 0 0 0 end
 sds 10 0 18 0 10 0 10 0 end
gend
point source
 fue 1 97.78 end
fend
 inn 1 89.218 98.79 end
 rs1 2 93.98 97.79 end
 our 1 99.06 111.76 end
 as1 1 89.218 99.79 end
 hol 1 end
 cav 4 86.36 97.79 end
cend
end
```

5.8.3 10-160b-pt-HAC.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt axial
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=0 ity=2 izm=5 isn=8 irf=9504 ifs=1 mhw=5 frd=86.36 szf=1  end
 86.36 89.218 93.98 99.06 199.06   end
 4 1 2 1 4   end
xend
 ran=000000091807 tim=120 nst=1000 nmt=4000 nit=1000 nco=4 ist=0 ipr=0
 iso=0 nod=16 sfa=1e+12 igo=4 inb=0 ine=0 mfu=5 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 22 78 0 0 0 0 0 0 0 0 end
```

```
 det 199.06 0 76.79 199.06 0 81.79 199.06 0 86.79 199.06 0 91.79 199.06
 0 96.79 199.06 0 101.79 199.06 0 106.79 199.06 0 111.79 199.06 0
 116.79 199.06 0 121.79 199.06 0 126.79 199.06 0 131.79 199.06 0
 136.79 199.06 0 141.79 199.06 0 146.79 199.06 0 151.79 end
 sdl 99.06 199.06 299.06 399.06 end
 sdr 70 120 70 140 70 90 70 90 end
 sds 10 0 14 36 0 0 0 0 end
 sxy 5 84.36 86.36 -1 1 95.79 97.79 86.36 97.79 99.06 111.76   end
gend
10-160b pt hac
 0 0 0 0
 sph 85.36 0 96.79 1
 rcc 0 0 -97.79 0 0 195.58 86.36
 rcc 0 0 -98.79 0 0 197.58 89.218
 rcc 0 0 -97.79 0 0 195.53 93.98
 rcc 0 0 -111.76 0 0 223.52 99.06
 sph 0 0 0 300
 sph 0 0 0 500
 rcc 0 0 -97.79 0 0 195.58 93.98
 rcc 0 0 -211.76 0 0 423.52 199.06
  end
 src +1
 cav +2 -1
 inn +3 -2
 shd +4 -3
 our +5 -8
 inv +6 -9
 exv +7 -6
 slp +8 -3 -4
 det +9 -5
  end
 1 1 1 1 1 1 1 1 1
 0 0 0 0 0 0 0 0 0
 5 4 1 2 1 1000 0 4 4
 0

end
```

5.8.4 10-160b-pt-igo0.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=0 ity=2 izm=5 isn=8 irf=9504 ifs=1 mhw=4 frd=1 szf=1  end
 1 86.36 89.218 93.98 99.06   end
 5 4 1 2 1   end
xend
 ran=000000111207 tim=120 nst=1000 nmt=4000 nit=10000 nco=4 ist=0 ipr=0
 iso=0 nod=0 sfa=1e+12 igo=0 inb=0 ine=0 mfu=5 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0
```

```
 0 0 22 78 0 0 0 0 0 0 0 0 end
 sdl 99.06 199.06 322 344 end
 sdr 0 20 0 100 0 100 0 10 end
 sds 5 1 10 1 10 1 1 1 end
gend
point source
 fue 1 97.78 end
fend
 inn 1 89.218 98.79 end
 rs1 2 93.98 97.79 end
 our 1 99.06 111.76 end
 as1 1 89.218 99.79 end
 hol 1 end
 cav 4 86.36 97.79 end
cend
end
```

5.8.5 10-160b-pt-n-axial-HAC.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt neutron
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=1 ity=1 izm=4 isn=8 irf=9029 ifs=1 mhw=3 frd=86.36 szf=1  end
 97.79 98.79 111.76 211.76   end
 4 1 1 4   end
xend
 ran=000000111607 tim=120 nst=1000 nmt=4000 nit=500 nco=4 ist=0 ipr=0
 iso=0 nod=9 sfa=1.1e+08 igo=4 inb=0 ine=0 mfu=3 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0.259 0.459 0.108 0.042 0.045 0.049 0.038 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 end
 det 45.36 0 211.76 55.36 0 211.76 65.36 0 211.76 75.36 0 211.76 85.36
 0 211.76 95.36 0 211.76 105.36 0 211.76 115.36 0 211.76 125.36 0
 211.76 end
 sdl 111.76 211.76 311.76 411.76 end
 sdr 80 90 0 150 80 90 80 90 end
 sds 0 0 15 36 0 0 0 0 end
 sxy 3 84.36 86.36 -1 1 95.79 97.79 86.36 97.79 99.06 111.76   end
gend
10-160b pt hac
 0 0 0 0
 sph 85.36 0 96.79 1
 rcc 0 0 -97.79 0 0 195.58 86.36
 rcc 0 0 -98.79 0 0 197.58 89.218
 rcc 0 0 -97.79 0 0 195.53 93.98
 rcc 0 0 -111.76 0 0 223.52 99.06
 sph 0 0 0 400
 sph 0 0 0 500
 rcc 0 0 -97.79 0 0 195.58 93.98
 rcc 0 0 -211.76 0 0 423.52 199.06
  end
```

```
 src +1
 cav +2 -1
 inn +3 -2
 shd +4 -3
 our +5 -8
 inv +6 -9
 exv +7 -6
 slp +8 -3 -4
 det +9 -5
  end
 1 1 1 1 1 1 1 1 1
 0 0 0 0 0 0 0 0 0
 3 4 1 2 1 1000 0 4 4
 0
 end
```

5.8.6 10-160b-pt-n-axial-igo0.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
end comp
 idr=1 ity=1 izm=3 isn=8 irf=9029 ifs=1 mhw=4 frd=1 szf=1  end
 1 97.78 111.76   end
 3 4 1   end
xend
 ran=000000091807 tim=120 nst=1000 nmt=4000 nit=500 nco=4 ist=0 ipr=0
 iso=0 nod=0 sfa=1.1e+08 igo=0 inb=0 ine=0 mfu=3 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 26 46 11 4 5 5 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 end
 sdr 0 100 0 100 0 10 0 10 end
 sds 10 0 10 0 1 0 1 0 end
gend
point source
 fue 1 97.78 end
fend
 inn 1 89.218 98.79 end
 rs1 2 93.98 97.79 end
 our 1 99.06 111.76 end
 as1 1 89.218 99.79 end
 hol 1 end
 cav 4 86.36 97.79 end
cend
end
```

5.8.7 10-160b-pt-n-HAC.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt neutron
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
```

```
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=0 ity=1 izm=5 isn=8 irf=9029 ifs=1 mhw=3 frd=86.36 szf=1  end
 86.36 89.218 93.98 99.06 199.06   end
 4 1 2 1 4   end
xend
 ran=000000091807 tim=120 nst=1000 nmt=4000 nit=1000 nco=4 ist=0 ipr=0
 iso=0 nod=10 sfa=1.1e+08 igo=4 inb=0 ine=0 mfu=3 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 0.259 0.459 0.108 0.042 0.045 0.049 0.038 0 0 0 0 0 0 0 0 0 0 0 0
 0 0 0 0 0 0 0 0 end
 det 199.06 0 57.79 199.06 0 67.79 199.06 0 77.79 199.06 0 87.79 199.06
 0 97.79 199.06 0 107.79 199.06 0 117.79 199.06 0 127.79 199.06 0
 137.79 199.06 0 147.79 end
 sdl 99.06 199.06 322 344 end
 sdr 70 120 0 140 80 100 80 100 end
 sds 10 0 14 36 10 0 10 0 end
 sxy 3 84.36 86.36 -1 1 95.79 97.79 86.36 97.79 99.06 111.76   end
gend
10-160b pt hac
 0 0 0 0
 sph 85.36 0 96.79 1
 rcc 0 0 -97.79 0 0 195.58 86.36
 rcc 0 0 -98.79 0 0 197.58 89.218
 rcc 0 0 -97.79 0 0 195.53 93.98
 rcc 0 0 -111.76 0 0 223.52 99.06
 sph 0 0 0 400
 sph 0 0 0 500
 rcc 0 0 -97.79 0 0 195.58 93.98
 rcc 0 0 -211.76 0 0 423.52 199.06
  end
 src +1
 cav +2 -1
 inn +3 -2
 shd +4 -3
 our +5 -8
 inv +6 -9
 exv +7 -6
 slp +8 -3 -4
 det +9 -5
  end
 1 1 1 1 1 1 1 1 1
 0 0 0 0 0 0 0 0 0
 3 4 1 2 1 1000 0 4 4
 0

end
```

5.8.8 10-160b-pt-n-igo0.inp

```
'Input generated by Espn 89 Compiled on 06-07-2002
=sas4     parm=size=500000
10-160B pt
27n-18couple  infhommedium
 carbonsteel 1 1 293 end
 lead 2 1 293 end
 beryllium 3 1 293 end
```

```
 arbm-air 0.0002 2 0 0 0 7014 82 8016 18 4 1 293 end
 cobalt 5 1 293 end
end comp
 idr=0 ity=1 izm=5 isn=8 irf=9029 ifs=1 mhw=4 frd=1 szf=1  end
 1 86.36 89.218 93.98 99.06   end
 3 4 1 2 1   end
xend
 ran=000000111307 tim=120 nst=1000 nmt=4000 nit=100 nco=4 ist=0 ipr=0
 iso=0 nod=0 sfa=1.1e+08 igo=0 inb=0 ine=0 mfu=3 isp=0 ipf=0 isd=4
 nda=1000  end
 soe 26 46 11 4 5 5 4 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 0 end
 sdl 99.06 199.06 322 344 end
 sdr 0 20 0 100 0 100 0 10 end
 sds 5 1 10 1 10 1 1 1 end
gend
point source
 fue 1 97.78 end
fend
 inn 1 89.218 98.79 end
 rs1 2 93.98 97.79 end
 our 1 99.06 111.76 end
 as1 1 89.218 99.79 end
 hol 1 end
 cav 4 86.36 97.79 end
cend
end
```

7.0 OPERATING PROCEDURE

This chapter describes the general procedure for loading and unloading of the 10-160B cask.

An optional steel insert may be used to shield the contents of the cask. The appropriate thickness of insert that should be used is determined from calculations and experience with previous, similar shipments. However, the insert must be thick enough so that dose rates on the exterior of the cask do not exceed the limits of 10 CFR 71.47, but must be no thicker than the maximum permissible size described in section 1.0.

The maximum permissible activity is the maximum activity in gammas/sec, determined per Attachment 1.

The maximum permissible payload of the cask is 14,500 pounds, including contents, secondary containers, shoring, and optional steel insert (if used).

For contents that could radiolytically generate combustible gases, the criteria of Section 4.8 must be addressed. For DOE TRU waste, compliance with the 5% hydrogen concentration limit shall be demonstrated by the methods discussed in Appendix 4.10.2. For other contents, which exceed the 5% concentration limit, the procedures in Section 7.4 can be used to satisfy the criteria of Section 4.8.

Powdered solids shipments require the cask to be leaktight. The most recent periodic leak test must meet the requirements of Chapter 4, Section 4.9, Periodic Verification Leak Rate Determination for Leaktight Status.

7.1 Procedure for Loading the Package

7.1.1 Determine if cask must be removed from trailer for loading purposes. To remove cask from trailer:

7.1.1.1 Loosen and disconnect ratchet binders from upper impact limiter.

7.1.1.2 Using suitable lifting equipment, remove upper impact limiter. Care should be taken to prevent damage to impact limiter during handling and storage.

7.1.1.3 Disconnect cask to trailer tie-down equipment.

7.1.1.4 Attach cask lifting ears and torque bolts to 200 ft-lbs ± 20 ft-lbs lubricated.

7.1.1.5 Using suitable lifting equipment, remove cask from trailer and lower impact limiter and place cask in level loading position.

NOTE **THE CABLES USED FOR LIFTING THE CASK MUST HAVE A TRUE ANGLE, WITH RESPECT TO THE HORIZONTAL OF NOT LESS THAN 60°.**

7.1.2 Loosen and remove the twenty-four bolts (24, 1¾" – 8 UN) which secure the primary lid to cask body.

7.1.3 Remove primary lid from cask body using suitable lifting equipment and the three lifting lugs on the secondary lid. Care should be taken during lid handling operations to prevent damage to cask or lid seal surfaces.

NOTE **THE CABLES USED FOR LIFTING THE LID MUST HAVE A TRUE ANGLE, WITH RESPECT TO THE HORIZONTAL OF NOT LESS THAN 45°.**

NOTE **IN CERTAIN CIRCUMSTANCES, LOADING MAY BE ACCOMPLISHED THROUGH THE SECONDARY LID AND THE PRIMARY LID WILL REMAIN ON. IN THIS CASE, THE FOLLOWING ALTERNATE (A) STEPS WILL BE USED:**

7.1.1.A (ALTERNATE) REMOVE THE IMPACT LIMITER CENTER COVER PLATE. THIS WILL PROVIDE ACCESS TO THE SECONDARY LID AND LIFTING LUGS.

7.1.2.A (ALTERNATE) WORKING THROUGH THE CENTER HOLE IN THE UPPER IMPACT LIMITER, LOOSEN AND REMOVE THE 12 1¾" – 8 UN LID BOLTS WHICH SECURE THE SECONDARY LID TO THE PRIMARY LID.

7.1.3.A (ALTERNATE) REMOVE THE SECONDARY LID USING SUITABLE LIFTING EQUIPMENT AND THE THREE LUGS ON THE LID. CARE SHOULD BE TAKEN DURING LID HANDLING

OPERATIONS TO PREVENT DAMAGES TO SEAL SURFACES OR THE LID

7.1.4 Visually inspect accessible areas of the cask interior for damage, loose materials, or moisture. Clean and inspect seal surfaces. Replace seals when defects or damage is noted which may preclude proper sealing.

NOTE **RADIOACTIVELY CONTAMINATED LIQUIDS MAY BE PUMPED OUT, REMOVED BY USE OF AN ABSORBENT MATERIAL, OR VIA DRAIN LINE. REMOVAL OF ANY MATERIAL FLOW INSIDE THE CASK SHALL BE PERFORMED UNDER THE SUPERVISION OF QUALIFIED HEALTH PHYSICS (HP) PERSONNEL WITH THE NECESSARY HP MONITORING AND RADIOLOGICAL HEALTH SAFETY PRECAUTIONS AND SAFEGUARDS.**

NOTE **WHEN SEALS ARE REPLACED (INCLUDING SEALS ON THE OPTIONAL VENT AND DRAIN PORTS), LEAK TESTING IS REQUIRED AS SPECIFIED IN SECTION 8.2.2.1.**

7.1.5 Check the torques on the cavity vent and drain line cap screws to determine that the cap screws are properly installed using O-rings. This step is not required if the cask does not have the optional vent and drain lines, or if the tamper seals on the vent or drain lines have not been removed. Torque the cap screws to 20 ± 2 ft-lbs.

7.1.6 Place radwaste material, disposable liners, drums, or other containers into cask and install shoring or bracing, if necessary to restrict movement of contents during transport.

7.1.7 Clean and inspect lid seal surfaces.

7.1.8 Replace the primary lid and secure the lid to the cask body by installing the 24 lid bolts. Ensure that the lid orientation stripe is in alignment with the cask stripe. Torque bolts to 300 ± 30 ft-lbs.

7.1.8.A (Alternate) Replace secondary lid (if removed) and secure to the primary lid with 12 bolts. Ensure that the lid orientation stripe is in alignment with the stripe on the primary lid. Torque the bolts to 300 ± 30 ft-lbs.

NOTE **PERFORM PRESSURE DROP LEAK TEST OF THE CASK PRIMARY LID, SECONDARY LID, VENT LINE, OR DRAIN LINE (AS APPLICABLE) IN ACCORDANCE WITH SECTION 8.2.2.2 PRIOR TO SHIPMENT OF PACKAGE LOADED WITH LARGE QUANTITIES OF LSA MATERIALS OR TYPE B QUANTITIES OF NON-LSA MATERIAL.**

7.1.9 Install anti-tamper seals to the designated lid bolts, or to vent and/or drain line plugs (if applicable).

7.1.10 If cask has been removed from trailer, proceed as follows to return cask to trailer:

7.1.10.1 Using suitable lifting equipment, lift and position cask into lower impact limiter on trailer in the same orientation as removed.

7.1.10.2 Unbolt and remove cask lifting ears.

7.1.10.3 Reconnect cask to trailer using tie-down equipment.

7.1.11 Using suitable lifting equipment, lift, inspect for damage and install upper impact limiter on cask in the same orientation as removed.

7.1.12 Attach and hand tighten ratchet binders between upper and lower impact limiters.

7.1.13 Cover lift lugs as required.

7.1.14 Install anti-tamper seals to the designated ratchet binder.

7.1.15 Replace center plate on the upper impact limiter.

7.1.16 Inspect package for proper placards and labeling.

7.1.17 Complete required shipping documentation.

7.1.18 Prior to shipment of a loaded package the following shall be confirmed:

(a) That the licensee who expects to receive the package containing materials in excess of Type A quantities specified in 10 CFR 20.1906(b) meets and follows the requirements of 10 CFR 20.1906 as applicable.

(b) That trailer placarding and cask labeling meet DOT specifications (49 CRF 172).

(c) That the external radiation dose rates of the 10-160B are less than or equal to 200 millirem per hour (mrem/hr) at the surface and less than or equal to 10 mrem/hr at 2 meters in accordance with 10 CFR 71.47.

(d) That all anti-tamper seals are properly installed.

(e) For powdered solids shipments, the most recent periodic leak test demonstrated the cask was leaktight.

7.2 Procedure for Unloading Package

In addition to the following sequence of events for unloading a package, packages containing quantities of radioactive material in excess of Type A quantities specified in 10 CFR 20.1906(b) shall be received, monitored, and handled by the licensee receiving the package in accordance with the requirements of 10 CFR 20.1906 as applicable.

7.2.1 Move the unopened package to an appropriate level unloading area.

7.2.2 Perform an external examination of the unopened package. Record any significant observations.

7.2.3 Remove anti-tamper seals.

7.2.4 Loosen and disconnect ratchet binders from the upper overpack assembly.

7.2.5 Remove upper overpack assembly using caution not to damage the cask or overpack assembly.

7.2.6 If cask must be removed from trailer, refer to Step 7.1.1.

7.2.7 (Optional if vent port installed). Vent cask cavity removing plugs from the vent line.

7.2.8 Loosen and remove the twenty-four (24) 1¾" – 8 UN primary lid bolts.

7.2.9 Using suitable lifting equipment, lift lid from cask using care during handling operations to prevent damage to cask and lid seal surfaces.

NOTE: THE CABLES USED FOR LIFTING THE LID MUST HAVE A TRUE ANGLE WITH RESPECT TO THE HORIZONTAL OF NOT LESS THAN 45°.

7.2.10 Remove contents to disposal area.

NOTE: RADIOACTIVELY CONTAMINATED LIQUIDS MAY BE PUMPED OUT, REMOVED BY USE OF AN ABSORBENT MATERIAL, OR VIA DRAIN LINE. REMOVAL OF ANY MATERIAL FROM INSIDE THE CASK SHALL BE PERFORMED UNDER THE SUPERVISION OF QUALIFIED HEALTH PHYSICS (HP) PERSONNEL WITH THE NECESSARY HP MONITORING AND RADIOLOGICAL HEALTH SAFETY PRECAUTIONS AND SAFEGUARDS.

7.2.11 Assemble package in accordance with loading procedure (7.1.7 through 7.1.17).

7.3 Preparation of Empty Packages for Transport

The Model 10-160B cask requires no special transport preparation when empty. Loading and unloading procedures outlined in this chapter shall be followed as applicable for empty packages. The requirements of 49 CFR 173.428 shall be complied with.

NOTE: EACH PACKAGE USER WILL BE SUPPLIED WITH A COMPLETE DETAILED OPERATING PROCEDURE FOR USE WITH THE PACKAGE.

7.4 Procedures for Shipment of Packages Which Generate Combustible Gases

Procedures for preparing packages for shipment which radiolytically generate combustible gases are outlined below. These procedures are divided into two categories:

a. Combustible gas control by inerting, and

b. Combustible gas suppression.

7.4.1 Combustible Gas Control by Inerting

7.4.1.1 Dewater the secondary container. The bulk of the free water is removed from the secondary container by displacing the water with nitrogen gas.

7.4.1.2 Inert the secondary container (and, if necessary, the cask). The inerting operation is done at the dewatering station just before the cask is loaded. Inerting is performed if the hydrogen generated will be greater than 5% in any portion of the package for a time period that is twice the expected shipping time. Inerting is intended to limit the oxygen concentration to less than 5% including any oxygen that is radiolytically generated over the same period considered for hydrogen generation. If a leak path can develop between the secondary container and the cask, the cask will also be inerted.

7.4.1.3 Inerting of the secondary container and / or the cask cavity, to achieve an oxygen concentration of less than 5%, can be performed per the following:

- Connect a nitrogen supply.
- Pressurize with nitrogen to 15 ±1 psig. for fifteen minutes.
- Depressurize to ~ 0 psig.
- Repeat this pressurization / depressurization cycle two more times

7.4.2 Combustible Gas Suppression

7.4.2.1 Dewater the secondary container. See paragraph 7.4.1.1.

7.4.2.2 Install the previously qualified* combustible gas suppression system (e.g., a vapor pressure catalytic recombiner).

*Previous qualification means that the catalytic recombiner design to be used has been tested for a period of twice the expected shipping time under conditions expected in transport and has proven satisfactory.

7.4.2.3 Sample the gas in the secondary container and measure static pressure. This will assure that the combustible gas control method is working properly and that the combustible gas criteria specified in Section 4.4 will be met.

7.4.2.4 Load the secondary container.

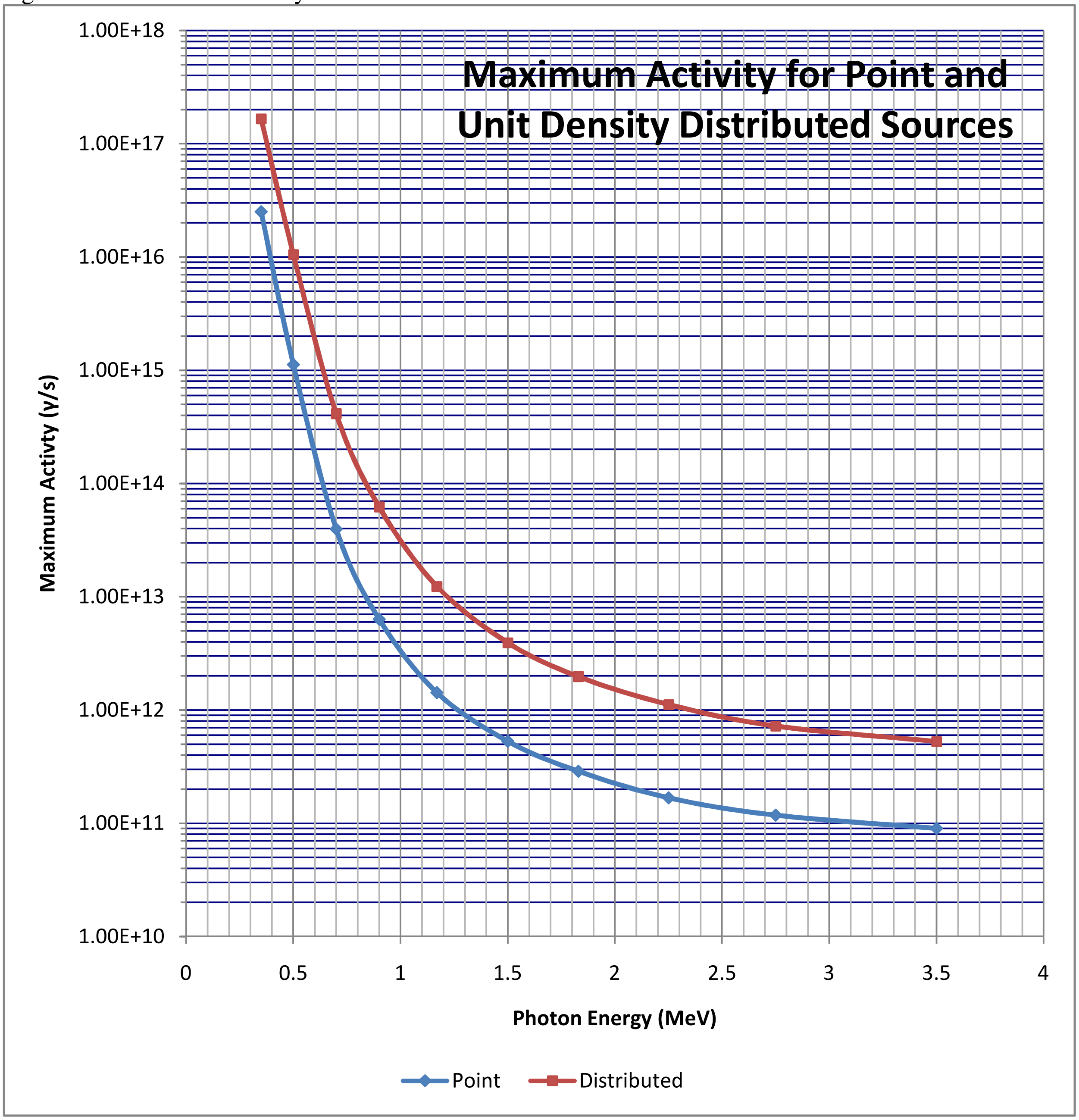
Attachment 1
Determination of Acceptable Activity
(see Chapter 5 for the derivation of the gamma activity limits)

1. Determine the total activity in the contents.
2. Determine if the content should be considered a distributed source. A distributed source is one that meets the definition of “distributed throughout” from NUREG-1608 and has a volume of at least 7.5 ft^3. If the content is a distributed source, determine the density (ρ) of the content, in g/cm^3.
3. Calculate the total gamma/sec for the contents by photon energy. Sum the photons per second by energy group, ignoring photon energies below 0.3 MeV. If any photons have energies above 4.0 MeV, the material is unacceptable for transport in the cask. Typical energy groupings (in MeV) are: 0.3-0.4, 0.4-0.6, 0.6-0.8, 0.8-1.0, 1.0-1.33, 1.33-1.66, 1.66-2.0, 2.0-2.5, 2.5-3.0, and 3.0-4.0. For contents with only a few energies, the actual photon energies may be used.
4. Determine the unit density gamma activity limit for the mid-point of each photon group (or for each photon energy) from Step 4 using the plot in Figure A-1. Use the point source or the distributed source limit as appropriate from Step 2.
5. If the content is a distributed source, calculate the Density Correction Factor (DCF) and multiply the unit density gamma limit by the DCF to determine the specific density gamma limit.

$$DCF = 0.7\ln(\rho)+0.98$$

6. Calculate the sum of fractions, i.e., divide the gamma/sec for each photon group (or for each photon energy) by the limit for that energy (or group) and sum the fractions.
7. If the sum is less than 1.0, the contents meet the activity limits of the CoC.

Figure A-1 – Gamma Activity Limits



Example 1 - Determine the acceptability of a 50 Ci Cs-137 source. The source is a metal capsule 2 cm in diameter and 10 cm long.

Step 1 The activity is 50 Ci

Step 2 The content is not a distributed source

Step 3 Cs-137 produces 0.85 gammas per decay with an energy of 0.66 MeV. The total gamma/sec is 3.7E+10 d/sec per Ci x 0.85 gamma/d x 50Ci = 1.57E+12 gamma/sec. All the gamma would be in energy group 0.6-0.8MeV.

Step 4 The limit for energy group 0.6-0.8 (mid-point energy = 0.7MeV) for a point source is 3.96+13.

Step 5 NA

Step 6 Sum = 1.57E+12 / 3.96E+13 = 0.04

Step 7 Sum is less than 1. The content meets the activity limits.

Example 2 – Determine the acceptability of a secondary container containing 100 ft^3 of solidified process waste. The activity is homogeneously distributed. The measured weight of the waste is 13,100 lbs. The isotopic activity, determined by analysis of samples of the waste, is: ^{60}Co-5 Ci, ^{137}Cs-10 Ci, ^{55}Fe-50 Ci, ^{54}Mn-4 Ci, ^{90}Sr-8 Ci

Step 1 The activity is 77 Ci

Step 2 The contents are a distributed source. The calculated density is 2.1 g/cm^3.

Step 3 See Table below

Step 4 See Table below

Step 5 DCF = $0.7\ln(\rho)+0.98$

DCF = 1.50

Step 6

Group No.	Group Mid-Point Energy (MeV)	Activity (photons/sec)	Unit Density Limit (photons/sec)	Specific Density Limit (photons/sec)	F
1	0.35	0.00E+00	1.66E+17	2.49E+17	0.00E+00
2	0.50	0.00E+00	1.05E+16	1.58E+16	0.00E+00
3	0.70	3.15E+11	4.12E+14	6.18E+14	5.10E-04
4	0.90	1.48E+11	6.18E+13	9.28E+13	1.60E-03
5	1.17	1.85E+11	1.23E+13	1.85E+13	9.99E-03
6	1.50	1.85E+11	3.93E+12	5.89E+12	3.14E-02
7	1.83	0.00E+00	1.97E+12	2.95E+12	0.00E+00
8	2.25	0.00E+00	1.12E+12	1.68E+12	0.00E+00
sum					4.35E-02

Step 7 F is less than 1. Thus, the contents meet the activity limits.