|  |  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- | --- |
| **CRITICALITY SAFETY EVALUATION**  **CSOL: xx0073**  **EVALUATION: XYZ-01**  **PAGE** 1 **OF 32** | | | | | | |
| OPERATION TITLE:  BUILDING:  AREA:  REVISION:  DATE OF EVALUATION:  DATE OF REVISION:  REASON FOR REVISION: | ***Hand-carrying of Pu-239 Canisters***  ***Pasqua Engineering Building***  ***(Entire building)***  ***0***  ***December 8, 20xx***  ***N/A***  ***N/A*** | | | | | |
|  | **NAME: SIGNATURE:** | | |  | **DATE:** | |
| Criticality Safety Engineer: |  | | |  | 12/8/xx | |
| Technical Reviewer: |  | | |  | 12/7/xx | |
| Managerial Reviewer: |  | | |  | 12/5/xx | |
| Operations Concurrence: | Ronald E. Pevey | | |  |  | |
|  |  | | |  |  | |
|  | | | | | | |
| Operations concurrence on this cover sheet indicates that they have read and understand the required physical and administrative controls, and acknowledge that they are controlled under CCCP. | | | | | | |
|  | | **REVIEWED FOR CLASSIFICATION** | | | |  |
|  | | By: |  | | |  |
|  | | Date: |  | | |  |
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# 1.0 INTRODUCTION

This Nuclear Criticality Safety Evaluation analyzes the transportation of 4-liter canisters containing Pu-239 during the packaging and shipping preparation processes of the Pu-239. Manual hand-carrying of the canisters is the transportation means analyzed for use during the process. The transportation period of interest begins with the removal of the 4-liter canisters from a shelved cabinet and is completed with the canisters being delivered to the glovebox where packaging will occur. The Pu-239 will there be weighed, combined into larger containers, and sent to the drum loading area. The larger canisters will then be loaded into a special shipping drum to be sent to a waste repository. The necessary postings for the process are found in Section 7.0 as generated by this analysis.

The hand-carrying of the canisters is essential to the packaging and shipping process to properly move the Pu-239 between various locations. This analysis is necessary to ensure that the handling process meets required safety standards and determine the required limits on the process for the canister contents to remain subcritical.

This evaluation was performed in accordance with Procedure SSOC-NCSI-040, Revision 0, *Instructions for Criticality Safety Evaluations* as well as the University of Tennessee *Nuclear Criticality Safety* manual, Revision 0.

# 

# 2.0 DESCRIPTION

The canisters containing the Pu-239 that are to be hand-carried are removed from a stainless steel cabinet resting on a 12-inch concrete floor. The canisters each have a capacity of 4-liters with a height-to-diameter ratio of 0.92. The transporting of the canisters is assumed to occur in one direction with no canisters returning to the cabinet via the same route. Thus carriers are not considered to meet during the transit process. For the purpose of this evaluation, the assumption is made that in the event of a canister being dropped, colliding with another object, etc. it will maintain its physical integrity as well as remain sealed. The canisters will be considered to have contact with the floor, cabinet, operator, glovebox, and other canisters from the time it is removed from the cabinet until it arrives at the glovebox.

The glovebox that canisters are to be carried to consists of stainless steel with a layer of lead mounted on the walls. It also rests upon the same type of concrete floor as the cabinet. The canister will be placed inside of the glovebox for packaging into a larger container once the hand-carry operation is completed.

***[NOTE from Professor: This evaluation was done BEFORE I started requiring the use of REAL containers in REAL places. I expect your description section to include a more detailed description than this example, with:***

***1. Photos of the container and the room.***

***2. Dimensions of container and room.***

***3. Materials of container and the significant reflecting materials in the room.]***

# 3.0 REQUIREMENTS DOCUMENTATION

There are no additional requirements unique to this evaluation.

# 

# 4.0 METHODOLOGY

This evaluation uses a combination of Monte Carlo reactivity calculations and knowledge of the physical configuration of the process equipment to demonstrate criticality safety for the hand-carrying of Pu-239 canisters during the packaging and shipping process. The primary basis for safety is fissile mass and volume control, with interaction between canisters and other objects also a factor in the overall safety basis. This evaluation relies upon controls and limits that were used to form parts of the safety bases for the hand-carry operation. These controls and limits are included in Section 7.0.

Calculations to provide the safety bases for the hand-carry operations were performed using the CSAS25 module of the SCALE41 code package. This module includes the cross-section processing codes BONAMI, NITAWL, and the three-dimensional Monte Carlo code KENO-V.a2. All cases run used SCALE 4.4a on a Pentium, using the 27GROUPNDF4 cross-section library. These calculations are covered by the validation study found in Appendix G. The maximum acceptable keff based on this validation is 0.929. [Note from professor: Be sure this agrees with Appendix G result.]

Validation of the codes and calculations was accomplished by comparison to benchmark experiments given in the International Handbook of Evaluated Criticality Safety Benchmark Evaluations3 (CSBE Handbook). The CSBE presents well-documented benchmark experiments in terms of both background information and benchmark calculational models. From this compilation, several relevant benchmarks were chosen and confirmatory calculations were performed. The benchmarks were chosen to provide validation for both the cross-section library and methodology. The complete validation study is included in Appendix G.

# 5.0 DISCUSSION OF CONTINGENCIES

For this evaluation a parameter-driven “What if?” analysis was performed to identify credible contingencies for this storage operation. In this type of analysis, consideration of the nine parameters that most directly affect criticality—fissile mass, enrichment, volume, geometry, concentration/density, moderation, interaction, reflection, and neutron absorption—guides an examination of the criticality vulnerabilities of a proposed operation or configuration.

Through this guided examination, the normal conditions (including abnormal anticipated conditions), the upset contingency events that challenge the normal conditions, and controls needed to protect these assumptions and assure sub-criticality are identified. The actual candidate contingency scenarios are developed from engineering judgment and operations experience.

The following sections provide the detailed results of the analysis by parameter, which are summarized in Table 5.1. [NOTE from professor: Make sure that detailed enough information is supplied in “Normal” to build the normal model

Table 5.1. Results of Contingency Analysis

|  |  |  |  |
| --- | --- | --- | --- |
| **Critical**  **Parameter** | **Normal** | **Contingency** | **Controls** |
| Mass | ~~20% overmass in canister~~  Maximum mass in unit is 3.1 kg. (An extra 20% was modeled for NDA uncertainty.) | 100% overmass in canister | * Postings define a maximum mass of 3.1 kg per a canister [7.1.1] * Operators trained on procedures and postings |
| Absorber | N/A | N/A | * ~~Analysis neither relies on nor uses absorbers~~   N/A |
| Geometry | H/D = 0.92 | N/A | * ~~Process uses cylinders with H/D=0.92~~ * Purchasing procedures specify canister dimensions [7.1.1] |
| Interaction | Single canister | Extra canister | * Procedure limits carrier to one canister [7.1.2] * Operators trained on procedures |
| Concentration | N/A | N/A | * ~~Process does not involve solutions~~   N/A |
| Moderation | 65% polyethylene by volume limiting matrix | ~~N/A~~  Canister flooded | * Procedure requires that containers be closed and locked * Purchasing specifications require water-tight containers |
| Enrichment | N/A | N/A | * ~~Worst possible enrichment (100% Pu-239) assumed~~   N/A |
| Reflection | Canister on floor in the corner of the room, surrounded by 12” thick slabs of water to represent nearby personel..~~against a surface or corner of the room~~  [NOTE from professor: The student should have made it clearer that “held” meant operator hands were around the canister.] | Canister fully reflected by sprinkler water. | * Building procedures require sprinkler system maintenance to assure proper operation * Sign-off maintenance sheet kept on sprinkler system |
| Volume | 10% increase in canister volume | N/A | * Purchasing rules require maximum size of canisters is 4 liters * Operators trained to recognize normal canister |

***[NOTE from Professor: This student should have had the Big Three—postings, procedures, and training on procedures— in the Controls boxes for Mass and Interaction.]***

## 5.1 MASS

[NOTE from professor: Be sure that every entry under “contingency” in Table 5.1 is represented here. And to give a reason why it is unlikely.]

***Contingency 5.1-1: 100% overmass in container***

This contingency consists of a 100% overmass condition in each container with the normal case volume. This contingency covers a situation in which extra mass is introduced by error without a volume limit violation. This contingency is unlikely because of….

## 5.2 Absorber

Absorbers are not ~~considered as a contingency or in the normal case~~ controlled since there are no absorbers present or involved in the process of consideration.

## 5.3 Geometry

Geometry is not considered in this analysis since the canister is already defined as a cylinder with a height-to-diameter ratio of 0.92. A second reason for ignoring geometry is the earlier assumption made that the canister will maintain its physical integrity if it is dropped.

## 5.4 INTERACTION

***Contingency 5.4-1: Two containers carried.***

This contingency consists of a common-cause situation in which mass and volume limits violations occur simultaneously due to the introduction of an extra container while the hand-carry occurs, each of which contains the normal case mass and volume. The extra container is considered to be a result of handling more than one canister. Due to the method of modeling, this contingency bounds the possibility of two operators colliding with one another. No other fissile materials are present during the process that require consideration.

***[NOTE from Professor: This student should have had a sentence along with each contingency beginning with* “This contingency is unlikely because…”]**

## 5.5 Concentration

Concentration is not ~~considered as a contingency or in the normal case~~ controlled since there are no solutions involved in the process.

## 5.6 Moderation

Moderation in the normal case is defined by the limiting matrix of 65% by volume of polyethylene. Moderation is not considered as a contingency since the canister is assumed to be water tight and that the lid will not come off if dropped. This eliminates the possible introduction of a moderator into the canister. [NOTE from Professor: Flooding should have been a contingency.]

## 5.7 ENRichment

Enrichment is not ~~considered as a contingency or in the normal case~~ controlled since the fissile material is 100% Pu-239. A change in concentration would only serve to decrease keff.

## 5.8 REflection

***Contingency 5.8-1: Complete reflection by personnel.***

***[NOTE from Professor: This student was counted off for not adequately supporting this as a contingency: He had no controls to prevent people from crowding around, so this should have been considered NORMAL. Besides, this was inconsistent with Table 5.1, which led me to expect full flooding.]***

This contingency consists of the reflection that occurs when a canister is completely surrounded by a crowd of people. Due to the method of modeling, flooding is bounded by this contingency and will not be considered separately. The normal case is based on consideration of a carrier holding a canister to close to a surface.

This contingency is unlikely because…

## 5.9 VOLUME

The normal case consists of 10% volume uncertainty. No further contingency is considered for volume.

***[NOTE from Professor: This student should have explained why a violation of the control listed in Table 5.1 is NOT a contingency.]***

Criticality accidents resulting from natural phenomena, such as earthquakes and tornadoes, are not considered CREDIBLE since the building is assumed evacuated and processes terminated if such an event would occur. With the termination of processes, the hand-carry procedure will cease and no canisters will be in transportation. Thus, a criticality accident is not considered feasible to occur for the hand-carry procedure.

# 6.0 EVALUATION AND RESULTS

## 6.1 CALCULATIONAL MODEL

### 6.1.1 Materials Discussion

Polyethylene is used as the limiting matrix material. In terms of reactivity modeling, fissile material in a poly matrix will produce a higher keff result than if the materials contained numerous tramp materials and unverifiable or unfounded water content. Polyethylene provides greater hydrogen content than water, as well as a non-trivial amount of carbon in place of the other tramp materials (i.e. iron, chlorides, fluorides, light metals, silicates, oxides, etc.) that would most likely serve as less-effective moderators. The materials used for the calculations of the models are listed in Appendix A in detail.

Materials Assumptions:

1. The concrete selected for use in this analysis is Oak Ridge concrete based on parametric study 1 in Appendix H. This concrete results in a higher keff in calculations compared to the other alternatives of the SCALE composition library. It composition can be found in Appendix A.
2. The fissile material is 100% Pu-239 with no other fissile material present in the process. This analysis is based upon the assumption that no other fissile material is present as a result of a previous process.
3. The stainless steel used in modeling the glovebox is based upon the composition found in the SCALE composition library. Its composition can be found in Appendix A.

### Model/Geometry Description

The model of analysis is based on a limitation of one canister being carried at a time. The canister is modeled as a 4-liter cylinder with a height-to-diameter ratio of 0.92. The walls of the canister are neglected on the basis of their small effect on keff as shown in parametric study 2 in Appendix H. The contents of the canister are defined as 3.1 kg of Pu-239 with 65% of canisters volume being modeled as polyethylene and the remainder of the volume being filled by air.

The canister is surrounded by 1-inch of water to simulate the hands of the carrier. The canister’s surrounding environment is based upon the most reactive location the canister may be placed during the hand-carry as is defined in parametric study 3. Thus the canister is modeled as being placed on/removed from the 12-inch concrete floor in the corner of the 12-inch concrete walls. The water-surrounded canister is placed in the corner with concrete slabs on three sides of it. To simulate a person placing or picking up a canister, the canister is boxed in with 12 inches of water on the three open sides with the top of the water beginning approximately 3 feet above ground floor. The analysis considers a 10% and 20% in measurement error for volume and mass respectively.

### Case Descriptions

The analysis modeled a 4-liter canister with added consideration taken for the 10% error in volume. For each mass of Pu-239 consider, this volume was applied as well as consideration for a 20% overmass. The mass considered as the normal case mass was 3.1 kg. The parametric study was run with consideration of three contingencies as discussed below.

(1) Mass. This contingency consists of a 100% overmass condition in each container with the normal case volume. Twice the normal Pu-239 mass in a 65% volume of polyethylene matrix was loaded into each canister of 110% of the normal volume

(2) Interaction. This contingency consists of two canisters being handled at the same instance during the normal process model. The two canisters each consist of 65% volume polyethylene and are modeled as a volume of 110% of the normal 4-liter volume. This contingency also bounds the possibility of two operators colliding with each other based on the modeling technique used.

(3) Reflection. This contingency consists of the reflection that occurs when a canister is completely surrounded by a crowd of people. Due to the method of modeling, flooding is also bounding by this contingency and will not be considered separately. The canister consists of 65% polyethylene by volume and is modeled as a volume of 110% of the normal 4-liter volume. This contingency also bounds the possibility of flooding due to sprinklers due to the modeling technique used.

## 6.2 Calculation results

.

The cases analyzed considered the three possible contingencies. The analysis involved a 4-liter canister (modeled as 4.4 to allow for allow for 10% measurement error). As shown in Table 6.1 the limiting contingency was determined to be that of a 100% overmass in the canister, for which keff + 2σ was less than the upper subcritical limit of 0.929 for normal mass loadings of 3.8 kg of Pu-239. Since the model considered the 20% error in mass measurements, the Pu-239 mass limit for the 4-liter canister during a hand carry is 3.1 kg. This is to be the posted mass limit.

Table 6.1 Results of Contingency Analysis

|  |  |  |  |  |  |
| --- | --- | --- | --- | --- | --- |
| Case | Mass (kg) | Volume (L) | Keff | σ | Keff + 2σ |
| Normal | 3.8 | 4.4 | 0.8189 | 0.0026 | 0.8241 |
| Double Mass | **7.6** | **4.4** | **0.9117** | **0.0025** | **0.9167** |
| Surrounded by Crowd | 3.8 | 4.4 | 0.8171 | 0.0026 | 0.8223 |
| Extra Canister  (Two of same dimensions) | 3.8 | 4.4 | 0.8859 | 0.0032 | 0.8923 |
| Note: Mass and volume values reflect 20% and 10% measurement errors respectively. | | | | | |

# 

***[NOTE from Professor: This student should have included a column with the actual name of the input file (under “CASE”) with the description words (“Normal”. “Double Mass”, etc.) in a column headed “Description” .]***

# 7.0 design features and administrative controls

## engineered safety features

This process neither involves nor relies on engineered safety features.

[NOTE from professor: Actually, this is not true, because the limitation on container size IS an Engineering Safety Feature. It would have been better if the student had included it here rather than rolling it into Control 7.1.1. It reads like he is casually mentioning that the canisters are limited to 4-liters, rather than requiring it.]

## POSTED CONTROLS

The following controls shall be posted on the storage cabinet that the canisters are to be removed from or if necessary within one foot as line-of-sight permits. The postings are shown in Appendix C.

Control 7.1.1: HAND-CARRY MAX of 3.1 kg per 4-liter canister

***Basis:*** *The mass limit is based on the evaluation of the model used for this analysis. 3.1 kg plus 20% was determined to be the limiting mass that remains subcritical.*

Control 7.1.2: MAX 1 canister carried at a time

***Basis:*** *The canister limit is based on the assumptions used during the model analysis. If necessary, scenario can be re-evaluated to allow for a second canister, as the process requires.*

# 8.0 summary and conclusions

This evaluation has determined that hand-carry operations can be performed safely with respect to criticality safety provided that mass and volume controls are implemented. Calculational parameter studies and reference to subcritical data have shown that the Pu-239 in the hand-carry process will remain subcritical for both normal and credible upset conditions.

Mass will be restricted according to the limits as listed in the postings, 3.1 kg. The contingency analysis considered mass overbatches, reflection of surfaces, and the presence of an extra container. Since the normal case was based upon the canister being placed on the floor, it can be considered safe to place the canister on the floor if necessary. All criticality scenarios were determined to be at least double contingent (no single process upset can cause a criticality).

[NOTE from professor: The student went a little overboard. The first paragraph was fine. Including the second paragraph just means that we would have to make sure it stays consistent with future revisions, which is an unnecessary pain.]

# 9.0 references

1*. SCALE: A Modular Code System for Performing Standardized Computer Analyses for Licensing Evaluation*, RISC Computer Code Collection, CCC-545, NUREG/CR-0200, Rev. 4, ORNL/NUREG/CSD-2/R4, Oak Ridge National Lab.

2. L. M. Petrie and N. F. Landers, *KENO-V.a - An Improved Monte Carlo Criticality Program With Supergrouping*, NUREG/CR-0200, Oak Ridge National Laboratory, December, 1984.

3. *International Handbook of Evaluated Criticality Safety Benchmark Experiments*, NEA/NSC/DOC(95)03/I-VI, Nuclear Energy Agency.

**APPENDIX A**

**MATERIALS AND COMPOSITIONS**

The following table shows the materials used in the analysis. The material composition and relative fraction of each component is also shown.

|  |  |  |  |
| --- | --- | --- | --- |
| Material | Density | Composition | Fraction (wt %) |
| ORCONCRETE | 2.294 g/cc | O | 42.01% |
| Ca | 32.13% |
| C | 17.52% |
| Si | 3.448% |
| Mg | 3.265% |
| Al | 1.083% |
| Fe | 0.7784% |
| H | 0.6178% |
| K | 0.1138% |
| Na | 0.0271% |
| Plutonium | 19.84 g/cc | Pu-239 | 100% |
| Polyethylene | 0.923 g/cc | CH2 | 100% |
| Stainless Steel 304 | 7.94 g/cc | Fe | 65.375% |
| Cr | 17% |
| Ni | 9.5% |
| Mn | 2% |
| Si | 1% |
| C | 0.08% |
| P | 0.045% |
| Water | 0.9982 g/cc | H2O | 100% |

**APPENDIX B**

**INPUT AND OUTPUT LISTINGS**

INPUT LISTINGS

The following listings include the input files for all of the cases quoted in this evaluation, in order that the results appear in this report, including the parametric studies that are referred to in Appendix H.

OUTPUT LISTING

All output listings of analysis cases and parametric studies are contained on the attached CD.

The following input was used to analyze the normal case.

#CSAS25 PARM=SIZE=500000

NORMAL

27GROUPNDF4 INFHOMMEDIUM

PU 1 0.04362 293 94239 100 END

POLY(H2O) 1 0.65 293 END

H2O 2 1 293 END

ORCONCRETE 3 1 293 END

END COMP

NORMAL

READ PARM GEN=203 NPG=500 RUN=YES PLT=YES END PARM

READ GEOM

UNIT 1

CYLINDER 1 1 9.1305 16.8 0

CYLINDER 2 1 11.6705 16.8 0

CUBOID 0 1 12 -12 12 -12 90 0

CUBOID 2 1 42.5 -12 42.5 -12 120.5 0

GLOBAL UNIT 2

CUBOID 0 1 500 0 500 0 500 0

HOLE 1 12 12 0.01

CUBOID 3 1 500 -30.48 500 -30.48 500 -30.48

END GEOM

READ BOUNDS ALL=VOID END BOUNDS

END DATA

END

The following input was used to analyze the double mass contingency.

#CSAS25 PARM=SIZE=500000

DOUBLE MASS

27GROUPNDF4 INFHOMMEDIUM

PU 1 0.08723 293 94239 100 END

POLY(H2O) 1 0.65 293 END

H2O 2 1 293 END

ORCONCRETE 3 1 293 END

END COMP

NORMAL

READ PARM GEN=203 NPG=500 RUN=YES PLT=YES END PARM

READ GEOM

UNIT 1

CYLINDER 1 1 9.1305 16.8 0

CYLINDER 2 1 11.6705 16.8 0

CUBOID 0 1 12 -12 12 -12 90 0

CUBOID 2 1 42.5 -12 42.5 -12 120.5 0

GLOBAL UNIT 2

CUBOID 0 1 500 0 500 0 500 0

HOLE 1 12 12 0

CUBOID 3 1 500 -30.48 500 -30.48 500 -30.48

END GEOM

READ BOUNDS ALL=VOID END BOUNDS

END DATA

END

The following input was used to analyze the contingency of the canister being surrounded by a crowd.

#CSAS25 PARM=SIZE=500000

CROWD

27GROUPNDF4 INFHOMMEDIUM

PU 1 0.04362 293 94239 100 END

POLY(H2O) 1 0.65 293 END

H2O 2 1 293 END

ORCONCRETE 3 1 293 END

END COMP

NORMAL

READ PARM GEN=203 NPG=500 RUN=YES PLT=YES END PARM

READ GEOM

UNIT 1

CYLINDER 1 1 9.1305 16.8 0

CYLINDER 2 1 39.48 16.8 0

GLOBAL UNIT 2

CUBOID 0 1 500 0 500 0 500 0

HOLE 1 40 40 0.01

CUBOID 3 1 500 -30.48 500 -30.48 500 -30.48

END GEOM

READ BOUNDS ALL=VOID END BOUNDS

END DATA

END

The following input was used to analyze the contingency of the presence of an extra canister.

#CSAS25 PARM=SIZE=500000

EXTRA CANISTER

27GROUPNDF4 INFHOMMEDIUM

PU 1 0.04362 293 94239 100 END

POLY(H2O) 1 0.65 293 END

H2O 2 1 293 END

ORCONCRETE 3 1 293 END

END COMP

NORMAL

READ PARM GEN=203 NPG=500 RUN=YES PLT=YES END PARM

READ GEOM

UNIT 1

CYLINDER 1 1 9.1305 16.8 0

CYLINDER 2 1 11.6705 16.8 0

GLOBAL UNIT 2

CUBOID 0 1 48 0 24 0 90 0

HOLE 1 12 12 0.01

HOLE 1 36 12 0.01

CUBOID 2 1 78 0 54 0 120.5 0

CUBOID 0 1 500 0 500 0 500 0

CUBOID 3 1 500 -30.48 500 -30.48 500 -30.48

END GEOM

READ BOUNDS ALL=VOID END BOUNDS

END DATA

END

**APPENDIX C**

**POSTINGS**

HAND CARRY **MAX** of

**3.1 kg**

per 4-liter canister

#### MAX 1

##### CANISTER

carried at a time

**APPENDIX D**

**COMMENT REVIEW SHEETS**

**[NOTE from professor: Yours should say “(Not used in this evaluation)”]**

|  |  |  |  |
| --- | --- | --- | --- |
| **#** | **Comment** | **Resolution** | **Initials** |
| 1 | Remove Appendix F page | Agreed it should remain in report | XYZ |
| 2 | Remove reference to Revision 3 | Reference removed | XYZ |
| 3 | Include a paragraph on QA procedure | QA paragraph added | XYZ |
| 4 | Remove posting #3 requiring removal only as needed (unnecessary with procedures) | Posting Removed | CDE |
| 5 | Show parametric study evaluations | Parametric studies added to output CD | CDE |
| 6 | Show normal case for geometry | Normal case added | CDE |
| 7 | Show normal case for interaction | Normal case added | CDE |
| 8 | Difficulty in reproducing exact keff | Difficulty attributed to difference in computers | CDE |
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**APPENDIX F**

**IDC LISTING FOR WET RESIDUES**

**(Not used in this evaluation)**

**APPENDIX G**

**CALCULATION VALIDATION STUDY**

Validation calculations were performed for this evaluation using the SCALE4.3 code package with the CSAS25 control module. The 27-group ENDF/B-IV cross section library was used for the validations to correspond with the calculations in the evaluation. All of the validation calculations were performed on the same type of Pentium computer used in the evaluation.

Benchmark cases were chosen to demonstrate the validity of the material cross sections used for the general range of moderation states and the calculational methodology (SCALE/KENO).

Four validation cases (listed below) were chosen from Reference ii. The cases represent calculational treatments of several critical experiments using Pu in a polystyrene matrix, reflected with plexiglass. These were chosen to validate the SCALE treatment of the polyethylene (carbon and hydrogen mixture) used in the evaluation cases. The chosen cases were run using the 27-group ENDF/B-IV cross sections as were used in the evaluation. (The ID numbers used in the results table below are taken from Ref. i.)

Ten of the validation cases were taken from the *International Handbook of Evaluated Criticality Safety Benchmark Experiments* (CSBE Handbook)3. Plutonium nitrate cases with varying fissile concentrations were chosen to study the SCALE treatment of plutonium systems involving a range of moderation states from H/Pu=171 up to H/Pu=774. Cases involving spheres of plutonium nitrate solution 11.5 inches, 12 inches, and 13 inches in diameter reflected by essentially infinite water reflectors (CSBE ID# PU-SOL-THERM-001, -002, and -003 respectively) were used. Fissile concentrations and H/Pu ratios are listed below.

The value of the upper subcritical limitis determined from the following equation:

Upper subcritical limit = 1.000 + bias - bias uncertainty - MSM

where MSM = Minimum Subcritical Margin

**Table G-1. Experiments Used for Validation**

| CSBE/UTNE  ID NUMBER | **kexp** | **kcalc** | **bias** |
| --- | --- | --- | --- |
| PU-SOL-THERM-001, CASE 1 | 1.000 | 1.015 | 0.015 |
| PU-SOL-THERM-001, CASE 2 | 1.000 | 1.014 | 0.014 |
| PU-SOL-THERM-001, CASE 3 | 1.003 | 1.022 | 0.019 |
| PU-SOL-THERM-001, CASE 5 | 1.000 | 1.021 | 0.021 |
| PU-SOL-THERM-003, CASE 1 | 1.000 | 1.010 | 0.010 |
| PU-SOL-THERM-003, CASE 2 | 1.002 | 1.000 | -0.002 |
| PU-SOL-THERM-003, CASE 5 | 0.998 | 1.016 | 0.018 |
| PU-SOL-THERM-003, CASE 6 | 1.000 | 1.017 | 0.017 |
| PU-SOL-THERM-002, CASE 3 | 1.000 | 1.014 | 0.014 |
| PU-SOL-THERM-002, CASE 4 | 1.000 | 1.016 | 0.016 |
| PO-014A | 1.000 | 1.026 | 0.026 |
| PO-015A | 1.002 | 1.024 | 0.022 |
| PO-016A | 1.000 | 1.024 | 0.024 |
| PO-017A | 1.000 | 1.021 | 0.021 |
|  |  | Average bias | 0.017 |
|  |  | Bias uncertainty  (3) | 0.021 |
|  |  |  |  |

***[NOTE from Professor: I expect you to pick and analyze 30-50 experiments.]***

As shown in the table above, all of the benchmark cases yield a keff very close to unity. The cases show a slight positive bias of 0.017 with a bias uncertainty of 0.021 (found from 3\*standard deviation of bias. As a matter of practice, no credit is taken for a positive bias, so the upper subcritical limit will be found from:

Upper subcritical limit = 1.000 - bias uncertainty – MSM = 0.979 - MSM

The minimum subcritical margin (MSM) is required by ANSI standards to be applied to criticality safety evaluations to ensure subcriticality. The MSM value is chosen depending on the following issues:

1. Does a thorough validation exist for the analysis method?
2. Has bias and bias uncertainty been determined for the analysis method using many data points from benchmark experiments with several independent experimenters?
3. To what degree are the process calculations within the area of applicability (AOA) of the validation calculations?
4. Is the system/process simple or complex?
5. Does the fissile material maintain its shape and composition during normal and credible abnormal events?
6. Are the physics and chemistry of the system/process understood?
7. How sensitive is the reactivity of the system to credible physical/chemical changes in the system?

These questions can be addressed as follows. The SCALE-4.3 criticality sequences, with the associated cross sections, have been the calculational method of choice for the criticality safety team for years. Thorough validations have been performed and documented for computer software and hardware used in this evaluation. For the particular validation effort for this study, fourteen experiments were included in the validation, thus providing a large number of data points from which to determine the bias and bias uncertainty. The experiments were performed at independent laboratories by independent researchers. As discussed below, the process calculations are in acceptable agreement with the area of applicability of the validation calculations after appropriate adjustments to the MSM are made.

The hand-carry process is simple. The material in the containers will not be changing composition. The container will neither gain nor lose mass or volume during the hand-carry process. Thus, there should be no reactivity changes in the system due to physical alterations of the containers environment that have not already been accounted for in the evaluation.

It is essential that the minimum subcritical margin be large enough so that reasonable changes to the system analyzed will not lead to an unsafe condition. Both the evaluation cases and benchmark cases model a range of moderations (except for the single moderation of the polystyrene experiments). The fission fractions for all of the cases modeled show that the systems are highly thermalized, with an overwhelming majority of fissions occurring in the energy group range of (generally) 20-27. The evaluation cases and the validation cases differ slightly in fuel composition, but the neutron behavior modeled in all cases is dominated by neutron moderation and/or reflection by carbon, hydrogen, and/or oxygen.

The examination of area of applicability for the evaluations versus the experiments is shown in Table G-2 below. The polyethylene matrix cases suffer from the relative scarcity of available comparisons for carbon-moderated systems. As can be seen in this table, the area of applicability for the evaluated cases and the polystyrene (carbon) experiments differs in the H/Pu range, the average energy group of fission, and (especially) the Pu-240 fractional content in the fuel. A value of 0.02 is often used for the MSM. Based on the analysis being somewhat outside the area of applicability provided by the experiments, we have decided to increase the MSM by 0.03 and use a value of 0.05. Thus, to allow for these differences, we use an upper subcritical limit of 0.929.

**Table G-2. Area Of Applicability (AOA) Comparison**

| Parameter | Range of Parameter in Experiments | Range of Parameter in this Analysis | Summary of AOA |
| --- | --- | --- | --- |
| 1. Fuel type and enrichment | 1.8 to 4.9%  Pu-240 | 0% Pu-240 | Significantly outside experiment range for both; more for the C cases |
| 2. Geometrical shape | Spheres | Cylinder | Outside AOA range, not significant 3D exact geometry in KENO. |
| 3. Interaction | Single units, multiple units, arrays | Arrays | Within AOA |
| 4.Moderation: H/X and C/X | Nitrate solution in water;  H/Pu=  171 to 774 | Polyethylene  H/Pu239 = 53 to 1163  C/Pu=27 to 582 | Outside AOA range; especially wide range for C |
| 5. Moderation: Average Energy Group of Fission  [NOTE from professor: You should use “Energy of average lethargy of fission (EALF)”] | 22.6 to 24.1 | 20.4 to 24.4 | Maximum keff for cases outside nitrate range is 0.852; therefore the important cases are within experiment range. |
| 6. Reflecting Material | Water and Stainless steel | Water, Lead, Concrete, and Stainless steel | Primarily H reflection for all cases |

This validation study was performed in accordance with Procedure UTK-NCS--09, Rev. 0, *Validating Reactivity Calculations*.

**APPENDIX H**

**PARAMETRIC STUDIES IN SUPPORT OF MODEL DEVELOPMENT**

**PARAMETRIC STUDIES IN SUPPORT OF MODEL DEVELOPMENT**

Parametric studies were conducted in the process of developing the models used in this analysis. These were designed to answer the following questions:

1. What is the worst concrete to use in modeling the floor?

1. What is the effect of ignoring the canister walls?
2. What is the worst placement for the canister?

Each of these will now be examined.

**Parametric Study 1: Determination of Worst Concrete Model**

[NOTE from professor: Parametric Study 1 is required. The other two were part of his model development.] The models of the evaluation were developed using a 12-inch concrete floor, assuming that the canisters can be placed directly on the floor. Only the concrete floor was considered in the modeling with any walls, surfaces, and etc. being neglected to determine the affects of the various types of concrete.

To test the impact of the four different types of concrete, the model used the maximum amount of Pu-239 by volume that could be held in the canister in accordance with the limiting matrix material and remain subcritical. This modeling consists of 25% Pu-239, 65% polyethylene (CH2), and 10% air. The canister modeled had a 7-inch diameter with a height-to-diameter ratio of 0.92. The keff for each of the four concretes is as follows:

|  |  |  |
| --- | --- | --- |
| Type of Concrete | keff | Uncertainty |
| ORCONCRETE | 0.9856 | 0.0029 |
| RFCONCRETE | 0.9815 | 0.0031 |
| REG-CONCRETE | 0.9835 | 0.0026 |
| MGCONCRETE | 0.9835 | 0.0031 |

The type of concrete that resulted in the highest keff was the Oak Ridge concrete. Therefore it will be the one used for modeling.

**Parametric Study 2: Effect of Wall Presence of Canister**

This parametric study determines the effect of modeling the canister with and without walls. The canister is modeled without walls with a 7-inch diameter and a height-to-diameter ratio of 0.92. The canister with walls adds a stainless steel-304 wall thickness of 1/16-inch. Both models surround the canister with 1-inch of water for simulation of hands. The canister contains 4 kg of Pu-239 and is polyethylene (CH2) by 65% volume with the remainder of the volume filled with air. The keff for each scenario is as follows.

|  |  |  |
| --- | --- | --- |
|  | keff | Uncertainty |
| With Canister Wall | 0.6361 | 0.0029 |
| Without Canister Wall | 0.6419 | 0.0029 |
| Effect of Canister Wall | 0.0058 | - |

The effect of the canister walls is approximately a 0.6% decrease in keff. The canister walls can thus be ignored and have a conservative keff.

**Parametric Study 3: Most Reactive Placement of Canister**

This parametric study determines the most conservative location to model the hand-carried canister that gives the highest keff. The canister is modeled containing 4 kg Pu-239, 65% polyethylene (CH2) by volume, and the remainder of the volume filled by air. The canister is modeled with a 7-inch diameter and a height–to-diameter ratio of 0.92 and is surrounded by 1-inch water to simulate hands. The canister will be modeled in three positions.

1. A corner surrounded by 12-inch concrete walls and floors.

2. A corner against a 12-inch concrete wall and floor and against a 3/16-inch

stainless steel-304 wall representing a cabinet

3. A corner against a 3/8-inch stainless steel-304 sheet with a 1/16-inch layer of

lead to represent the glovebox and a 12-inch concrete wall. This model applies

a conservative location of the glovebox being against a wall.

This analysis does not take into account the presence of any other canisters. The results for each placement are shown below.

|  |  |  |
| --- | --- | --- |
| Position | keff | Uncertainty |
| 1 | 0.7565 | 0.0030 |
| 2 | 0.7271 | 0.0030 |
| 3 | 0.6592 | 0.0029 |

Based on this parametric study the worst modeling of reflection in regards to canisters location occurs when the canister is placed on the concrete floor in the corner of the walls.