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WIPP Title I Operator Dose Calculations LATA Report #90

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FINAL REPORT
Waste Isolation Pilot Plant
Title I Operator Dose Calculations
for
Sandia Laboratories, Albuquerque, New Mexico
by
Los Alamos Technical Associates, Inc.
November 15, 1979

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WIPP Title I Operator Dose Calculations

LATA Report #90

by

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November 15, 1979

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ABSTRACT

The radiation exposure dose was estimated for the Waste Isolation Pilot Plant (WIPP) operating personnel who do the unloading and transporting of the transuranic contact-handled waste. Estimates of the radiation source terms for typical TRU contact-handled waste were based on known composition and properties of the waste. The operations sequence for waste movement and storage in the repository was based upon the WIPP Title I data package. Previous calculations had been based on Conceptual Design Report data. A time and motion sequence was developed for personnel performing the waste handling operations both above and below ground. Radiation exposure calculations were then performed in several fixed geometries and folded with the time and motion studies for individual workers in order to determine worker exposure on an annual basis.

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1.0 INTRODUCTION

This report was prepared at the request of the Nuclear Waste Engineering Division, Sandia Laboratories, Albuquerque, New Mexico, in order to determine the radiological impact of low-level waste on normal operations at the Waste Isolation Pilot Plant (WIPP). The radioactive source models and characteristics were developed from Title I design documents and data developed at Sandia.¹ Time and motion studies were developed from operations sequences outlined in the Title I design package with assistance from Sandia personnel and from the actual timing of certain operations by Sandia and Los Alamos Technical Associates, Inc. (LATA) personnel.

1.1 Objectives

The primary objective of the study was to update the findings of a previous report² by using new facility layouts and operations sequences from Title I design information. Secondary objectives were to improve the radiation source characterization and to attempt to verify the degree of accuracy of the dose-rate calculations.

1.2 Approach

The approach for obtaining operator annual dose exposure was to estimate the dose-rate field around various waste configurations in WIPP and to fold this with the operator distance at appropriate times as determined by the time and motion study. No shielding was assumed for this study. The dose rates were estimated by using a semianalytical technique.

1.3 Results, Highlights

All dose exposures were within allowable and desirable limits except for cases where waste drums were handled one-at-a-time. The dose exposures for those cases are still within allowable limits but is above

the desirable limit of 1 rem per year. The results are somewhat conservative, and the dose obtained is estimated to be at least a factor of two high. Even with this conservatism, it appears that some shielding would be required for the single-drum operations should an alternate handling method not be selected.

2.0 OPERATIONS ANALYSIS

An analysis of the transuranic (TRU), contact-handled (CH) waste operations was performed to arrive at estimates of the radiation exposure to certain operating personnel. The personnel who are closest to the radiation source (waste containers) for the greatest period of time are the operators who transport the waste within the WIPP facility. Therefore, this analysis concentrated upon these personnel.

The waste to be handled through the WIPP facility has a sufficiently low surface dose rate (less than 200 mrem per hour) that it can be contact-handled.¹ The shipping containers are checked for transferable alpha contamination, and any leaking or damaged storage containers are repaired, cleaned, or overpacked if necessary. Then the storage containers (drums or boxes) are loaded by forklifts onto large reusable pallets, lowered to the underground storage level, and transported through the repository to the storage site, where they are unloaded from the pallets and stacked in the room, again by a forklift. The reusable pallets are returned to the surface facility for reloading.

A prerequisite for calculating the nuclear radiation exposure of operating personnel in the TRU waste facility was a reasonably detailed time and motion (T&M) estimate. This involved estimating the various operator-to-source distances as a function of time; that is, a history of each operator's line-of-sight exposure range. When these histories are mapped onto the exposure dose rate contours, the accumulated radiation exposure can be calculated.

2.1 Time and Motion Scenarios

The T&M study concentrated upon the operators who are to transport the CH waste. These pertinent operations are outlined in Table 2-1. Sketches and more detailed information are provided in Appendix A.

TABLE 2-1
OUTLINE OF PERTINENT WIPP OPERATIONS

-
- Unload shipping containers from railcars and trucks.
 - Unload drums, six-packs, and boxes from shipping containers.
 - Load drums, six-packs, and boxes onto pallets.
 - Load two pallets on mine hoist transfer car.
 - Lower loaded pallet to CH underground storage level.
 - Load individual pallets onto underground transporter.
 - Transport pallets to CH storage rooms.
 - Stack six-packs and boxes in storage room.
 - Load empty pallets into hoist cage for return to surface facility.
-

This study considered several waste-handling operator scenarios for the underground operations and the aboveground operations. These scenarios are outlined in Table 2-2. The radiation exposure sources are outlined in Table 2-3.

2.2 Underground Operations

For the underground operations, two individuals will be in the vicinity of the low-level waste for significant portions of time. These are the forklift operator in the storage room and the pallet transporter operator. The operator of the 15-ton forklift, used to load the pallets from the lower-level hoist cage to the pallet transporter, is considered to have a relatively minor radiation exposure; therefore, this operation is not analyzed in this study. The sequence of operations in the underground facility is illustrated in Table 2-4. Most of the wastes arrive in six-packs of 55-gal drums and modular steel boxes.

TABLE 2-2

TIME AND MOTION ANALYSIS CASES

<u>Case No.</u>	<u>Description</u>
1.1	Underground storage room forklift operator, handling individual drums, 32-ft-wide room
1.2	Underground storage room forklift operator, handling six-packs or modular steel boxes, 32-ft-wide room
1.3	Underground storage room forklift operator, handling six-packs or modular steel boxes, 45-ft-wide room
2.1	Underground pallet transporter operator, 32-ft-wide room
2.2	Underground pallet transporter operator, 45-ft-wide room
3.1	Aboveground shipping container forklift operator (Title I, scheme #1), unloading individual drums
3.2	Aboveground shipping container forklift operator, unloading six-pack or modular steel boxes
3.3	Aboveground shipping container forklift operator, (Sandia concept), unloading six-packs or modular steel boxes
4	Aboveground pallet shuttle forklift operator

TABLE 2-3

RADIATION EXPOSURE SOURCES

Underground

1. Storage Room Forklift Operator
 - a. Dose from stack
 - b. Dose from waste being carried
 - c. Dose from pallet
2. Transporter Operator
 - a. Dose from pallet

Aboveground

3. Shipping Container Unloading Forklift Operator
 - a. Dose from shipping container stack
 - b. Dose from waste being carried
 - c. Dose from staging area pallet
 - d. Dose from surge area
 4. Pallet Shuttle Forklift Operator
 - a. Dose from pallets in staging area
 - b. Dose from pallet being carried
 - c. Dose from surge storage area
-

TABLE 2-4

SEQUENCE OF OPERATIONS
FOR
ANALYSIS OF UNDERGROUND FACILITIES

-
1. Down-shaft arrival of loaded pallet every 28 minutes.
 2. Loaded pallet placed on TRU waste transporters and carried approximately 3,600 ft to storage room.
 3. Transporter parks in haulage drift at end of a 32-ft-wide, 300-ft-long storage room (specifically where crosscut intersects haulage drift).*
 4. Forklift operator attaches to load with appropriate coupler.**
 5. Forklift trams load to face of stack at end of storage room (average of 150 ft).
 6. Forklift operator positions and stacks load.
 7. Forklift operator trams back to pallet to repeat sequence.
 8. After pallet is unloaded (approximately 12 minutes), forklift operator trams out of storage room and waits for next pallet in an area of minimal exposure such as the haulage drift.
 9. Transporter returns to hoist area with the empty pallet.

* A 45-ft-wide room that allows the transporter to enter and turn around is also considered in the analysis.

** Pallet may contain any of four kinds of TRU waste containers:

- (1) individual 55-gal drums,
 - (2) six-pack of 55-gal drums,
 - (3) modular steel boxes, or
 - (4) steel, overpacked, fiber glass-reinforced polyester (FRP) plywood boxes.
-

2.2.1 T&M Estimates for Underground Storage Room Forklift Operation

The time estimates for the forklift operations were based upon actual stopwatch timings of operations with current generation equipment at Sandia's warehouse at Kirtland Air Force Base, New Mexico. The times estimated for forklift handling of (1) individual drums, (2) drum six-packs, or (3) modular steel boxes were essentially the same. Therefore, no distinction is made in the estimated operation elapsed time.

Sketches of these operations are included in Appendix A along with details of the time and motion analyses.

The time estimates for forklift operations in the 32-ft-wide room are as follow:

	<u>Operation</u>	<u>Elapsed Time</u> (Assumes 80% Efficiency Factor)
Step 1	Position at pallet, engage or clamp onto drums and lift off pallet.	29 sec
Step 2	Back up and turn 180 degrees.	16 sec
Step 3	Tram from pallet to stacks, an average of 150 ft at 5 ft/s.	30 sec
Step 4	Position drums at the stack, lift into place and unload.	54 sec
Step 5	Back up and turn 180 degrees.	16 sec
Step 6	Tram back to the pallet.	<u>30 sec</u>
	Total time per cycle	175 sec

2.2.1.1 Case 1.1 Results

If the underground forklift handles the drums individually within a 32-ft-wide room, 70 minutes are required to unload each pallet. The detailed time and motion history is given by Table A-5 in Appendix A. A total of 16-1/3 forklift-hours are needed to handle the daily total ingress of drums.

2.2.1.2 Case 1.2 Results

As worked out in Appendix A, the storage room forklift operator needs about 12 minutes to unload and stack the six-packs or boxes on each pallet. For the average total of 12 pallets per shift day, the operator only needs to work about 2.4 hours; the remaining nearly 4.6 hours of usable shift time will not need to be spent in the radiation exposure area and will thus not be considered to add to the operator's accumulated dose. It appears that the storage room forklift operator could more efficiently be utilized if he were also to drive the pallet transporter. The transporter operator will have to wait while the forklift unloads the pallet and, conversely, the forklift operator will spend over half his time waiting for the next pallet to arrive.

The T&M analysis given by Table A-5 illustrates the operator-to-source exposure history of a single handling cycle.

2.2.1.3 Case 1.3 Results

When a 45-ft-wide room is assumed, the transporter can enter and park within 50 ft of the stack. The T&M history is illustrated by Table A-6 in Appendix A. The four cycles to unload a pallet of six-packs or boxes require 8 3/4 minutes. For the daily average of 12 pallets of six-packs and boxes, the total exposure time for the forklift operations is about 1-3/4 hours.

2.2.2 T&M Estimates for Underground Transporter Operator

This T&M analysis involved the exposure to the driver and/or helper of the CH waste transporter. This special truck transports a loaded pallet from the hoist off-load station to the storage area and then returns an empty pallet for the hoist to carry to the surface for a repeat of the cycle.

If the transporter operator also operates the storage room forklift, his radiation dose can be estimated by adding the dose from the forklift operations.

2.2.2.1 Case 2.1 Results

The pallet transporter operator moves a single, fully loaded pallet from the hoist off-load station to the storage room where he waits outside the line-of-sight of the waste stack. This results in a constant dose at a slant range of 13 ft for 17 minutes per pallet or 204 minutes per 8-hour shift.

2.2.2.2 Case 2.2 Results

In this instance, the pallet transporter operator is exposed to the full pallet he is transporting for about 17 minutes per trip. In addition, he is exposed to (1) the storage room stack at a distance of 50 ft for about 9 minutes per trip and (2) the partially unloaded pallet for about 4-1/2 minutes per trip. The net results are exposures of (1) full pallet dose at a slant range of 13 ft for 258 minutes per 8-hour shift, and (2) storage room stack dose at a range of 50 ft for 108 minutes per 8-hour shift.

2.3 Aboveground Operations

The exposure of the forklift operators was analyzed for the aboveground (surface facility) operations. Several different types of waste containers will probably be received at the WIPP surface facility. However, this analysis only considered the most prevalent waste containers and geometries, that is, individual 55-gal drums, six-packs of drums, and pallets. It was felt that this was justified because the other containers such as FRP boxes and modular steel boxes will have an insignificant impact on the overall handling operations because, as explained in Section 3.0, these containers generally have a lower radiation surface dose rate. The radiation dose from the various types of waste containers is discussed in Appendix C. Three separate operations were considered: 1) unloading the incoming shipping containers from railcars and trucks (Title 1 concept); 2) unloading the incoming shipping containers (Sandia version 9/79); and 3) pallet shuttle to the hoist cage.

The present Title I operations call for individual drums to arrive in the railcar and truck shipping containers. Currently, serious consideration is being given to receiving and handling the drums in banded six-packs; therefore, this analysis considers both situations. The sequence of the aboveground operations is outlined in Table 2-5.

2.3.1 T&M Estimates for Case 3.1: Aboveground Shipping Container Unloading (Individual Drums)

This Title I concept calls for the waste drums to be stacked individually in the shipping containers (supertiger or cargo container). This necessitates unloading 333 drums on a design basis day; that is 333 forklift trams to and from the pallet staging area.

2.3.1.1 Case 3.1 Results

The estimated cycle time for loading a drum on the near side of the pallet is 106 seconds; conversely, 129 seconds are required to load to the far side of the pallet. If the average cycle time is 118 seconds, it takes a total of 10.7 forklift hours to unload and handle the average daily influx of drums. The previously published rate (SK-41-F-004 and SK-41-F-005, Revision 4/11/79, of Reference 3) for shipping container unloading was 165 seconds per cycle as compared to the 118 used in the present study.

The slant range distance from the operator to each of the significant radiation sources is given in Appendix A, Tables A-7 and A-8.

2.3.2 T&M Estimates for Case 3.2: Aboveground Shipping Container Unloading (Six-Packs or Modular Steel Boxes)

In this instance, the waste is assumed to be unloaded from the shipping containers in the form of an 80/20 mixture of six-packs and modular steel boxes. For the average day, this results in 9.63 pallets of six-packs and 2.4 pallets of boxes assembled in the pallet staging area.

TABLE 2-5

SEQUENCE OF NORMAL OPERATIONS FOR ANALYSIS OF
ABOVEGROUND FACILITIES

-
1. TRU waste arrives in special shipping containers via trucks or rail cars.
 2. The shipping containers are off-loaded and carried to the CH handling area via a bridge crane.
 3. A ramp is placed into the open end of the shipping container for unloading.
 4. A forklift then unloads the TRU waste from the shipping container and stacks it (drums or modular steel boxes) in a single level on the transport pallets.
 5. The pallet shuttle forklift (15-ton capacity) trams the full pallets to the CH airlock where they are stacked two-high and lowered by the hoist to the storage level (approximately 2,150 ft below the surface).
 6. If the CH airlock is momentarily full, the shuttle forklift places the loaded pallets in the surge storage area.
 7. The pallet shuttle forklift periodically removes and relocates empty pallets that have been hoisted up from the storage level.
 8. Any shipping containers that are contaminated from leaking barrels or boxes are handled in the overpack and repair room. This is expected to be an infrequent occurrence; consequently, it will have an insignificant impact on the normal operational flow of waste and is not considered in the time and motion analysis.
-

2.3.2.1 Case 3.2 Results

The average cycle time for loading a six-pack or box, from the shipping container to the pallet, is 118 seconds. This cycle time is the same as that for Case 3.1; but, in this case, to unload each day's ingress of six-packs and of boxes requires only 1-1/4 hours and 1/3 hours, respectively.

The radiation source-to-operator distances and times are also given in Appendix A, Tables A-7 and A-8. Those are the same as for Case 3.1; however, now six times fewer cycles are needed.

2.3.3 T&M Estimates for Case 3.3: Aboveground Shipping Container Unloading (Sandia Version 9/79)

This CH waste container handling concept calls for a single forklift to unload the shipping containers and tram them to a pallet staging area where a conveyor loads them into the CH airlock to be loaded into the hoist cage. This process sequence and layout (as shown in Appendix A, Figure A-14) is designated as the Sandia version 9/79.

2.3.3.1 Case 3.3 Results

An estimated 129 seconds are required to complete a six-pack handling cycle from shipping container to pallet and return. The number of cycles required to process the average day's ingress of waste is 48 cycles. Therefore, the total time for forklift operation is about 1-3/4 hours per day. This applies to any configuration of six-packs and modular steel boxes, since their handling cycle times are estimated to be the same.

The time-dependent slant ranges to the four significant radiation sources are given in Appendix A, Table A-9.

2.3.4 T&M Estimates for Case 4: Aboveground Pallet Shuttle Forklift Operation (Title I)

A 15-ton forklift is planned to move the loaded pallets from the pallet staging area to the pallet transfer car that loads the pallet hoist (Title I concept). Appendix A, Figure A-15, illustrates the geometry of this scenario. The forklift operator is exposed to radiation from three significant sources: (1) the pallet staging area, (2) the pallet being transported, and (3) the surge storage area.

2.3.4.1 Case 4 Results

It takes an estimated 144 seconds to unload and handle each pallet. On an average day, the number of pallets to be transferred to the hoist cage is only 12; therefore, the total forklift operation time will be only about 1/2 hour per day. The previously published rate (SK-41-F-004 and SK-41-F-005, Revision 9/11/79, Reference 3) for pallet handling is 180 seconds per cycle as compared to the 144 seconds used in the present analysis.

The time-dependent slant ranges to the radiation sources are given in Appendix A, Table A-10.

3.0 PERSONNEL RADIATION EXPOSURE

The personnel radiation exposures were calculated with semianalytic techniques used in the previous operator dose study.² Calculations were performed for a single drum and a stack in the underground storage room in order to compare the results of the semianalytic technique with those of a more accurate Monte Carlo method (see Appendix B). The two sets of results compared well, with the semianalytic technique overestimating the dose rate by approximately a factor of two at distances of importance. Use of the semianalytic technique for all of the waste configurations simplifies the calculation and adds built-in conservatism to the results. The results of these calculations are shown in Appendix C.

The radiation calculations used drums and combinations of drums to represent the waste sources. This is because the FRP boxes represent a smaller and more dispersed source, and the modular steel boxes have more shielding than the drums, as explained in Appendix C. Using drums is the conservative approach.

3.1 Exposure Estimates for Underground Storage Room Forklift Operation

The dose rate mappings from Appendix C for the underground stack, the drums being transferred, and the pallet were used to estimate the radiation exposure to the forklift operator. The time and motion information (durations and distances) developed in Appendix A were folded with the dose-rate information to estimate the exposures. For a year (40 hours per week, 50 weeks per year), the operator is exposed to about 4.7, 0.9, and 1.1 rem of gamma radiation for Cases 1.1, 1.2, and 1.3, respectively. About 75% of this dose exposure is from the underground stack. This is within allowable limits, but Case 1.1 would require shielding to remain below the desired limit of 1 rem per year.

3.2 Exposure Estimates for Underground Transporter Operation

For Case 2.1, the underground transporter operator is exposed to a pallet at a distance of about 13 ft for 17 minutes per pallet. The

constant dose rate is approximately 0.015 mrem per hour, giving him a dose exposure of only 81 mrems over the course of a year (see Appendix C). The underground transporter operator for Case 2.2 is also exposed to the underground stack for 9 minutes at a distance of 50 feet. The dose exposure in this case is about 108 mrem per year, also very low. This is an extremely small dose and well within allowable limits. In fact, it is below natural background.

3.3 Exposure Estimates for Aboveground Shipping Container Unloading

The operator in Case 3.1 unloads the drums individually from the shipping container. Assuming that two forklift operators are used in this case, the analysis in Appendix C shows that the dose exposure could be as high as 1.7 rems per year. This is not above the allowable but is more than desirable, and the use of this container unloading sequence would require a shielded forklift cab. The relatively high dose is due not only to the longer time that the operator is exposed to his load, but also to the increased times that he is exposed to drums in the shipping container, the CH handling area, and the surge storage area.

For Case 3.2, the dose exposure is reduced to 318 mrem per year.

3.4 Exposure Estimates for Aboveground Pallet Shuttle Forklift Operation

The analysis of Appendix C concludes that the aboveground pallet shuttle forklift operator (Case 4) receives only about 100 mrems per year, well within allowable limits.

3.5 Exposure Estimates for Aboveground Shipping Container Unloading (Sandia Version 9/79)

In Case 3.3, the operator, instead of unloading the drums one-at-a-time, unloads them by the six-pack and carries them directly to the CH airlock with no intermediate steps. As Appendix C shows, this reduces this operator's dose exposure from the 1.7 rems per year of

Case 3.1 (see Table 4-1 and Subsection 3.3) to about 426 mrem per year. This is within allowable and desired limits and would not require shielding.

4.0 CONCLUSIONS AND RECOMMENDATIONS

The estimated radiation exposures of the various WIPP operating personnel are shown in Table 4-1. Shielding in the form of shielded forklift cabs may be required in Cases 1.1 and 3.1.

TABLE 4-1

RESULTS OF OPERATOR DOSE CALCULATIONS

<u>Case</u>	<u>Description</u>	<u>Dose *</u> <u>(mrem/yr)</u>
1.1	Forklift Operator - Underground	4,680
1.2	Storage Room	912
1.3		1,056
2.1	Transporter Operator - Underground	81
2.2		108
3.1	Forklift Operator - Shipping	1,686
3.2	Container Unloading	318
3.3		426
4	Forklift Operator - Pallet Shuttle	100

* Assumes surface dose rate of 3 mrem/hour for drum.

Recommendations

- All forklift operations should be simplified by requiring that all the received drums be previously banded into six-packs or that modular steel boxes be used.
- The underground waste container handling should be made more efficient and probably safer by having the forklift operator also drive the pallet transporter (there is easily enough time for one person to do both operations).

- During Title II, a study is recommended to assess hazards to other waste-handling workers who may have significant radiation exposures; these workers include the salt backfill crew, the health physics crew performing checks for incoming contaminated waste containers, and the crew overpacking leaking waste containers. In case one of the operations in WIPP is banding drums into six-packs, the dose exposure to the banding crew should be evaluated.

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APPENDIX A
TIME AND MOTION STUDY FOR WIPP TITLE I
CH WASTE HANDLING OPERATIONS

APPENDIX A
TIME AND MOTION STUDY FOR WIPP TITLE I
CH WASTE HANDLING OPERATIONS

The transuranic (TRU) waste to be handled through the TRU facility has a surface dose rate of 200 mrem/hr or less.¹ Containers are checked for possible leakage and contamination, they are cleaned or overpacked if necessary, then loaded by forklifts onto large reusable pallets, lowered to the storage level, transported through the mine to the storage room, where they are unloaded from the pallets and stacked in the storage room, again by forklifts. The reusable pallets are returned to the surface facility for reloading.

A prerequisite for calculating the nuclear radiation exposure of the waste-handling personnel in the TRU waste facility is a reasonably detailed time and motion (T&M) estimate. This involved estimating the various operator-to-source distances as a function of time, that is, a chronology of each operator's line-of-site exposure range to the radionuclide sources. When these histories are mapped onto the exposure dose rate contours, the accumulated radiation exposure can be calculated.

A.1.0 OPERATIONS ANALYSIS

This analysis concentrated on those operations where personnel are most frequently within reasonable proximity of stored or transported contact-handled waste. These operations are outlined in Table A-1. The operating personnel of prime interest are the forklift and transporter operators in the normal process flow in the aboveground receiving facility and the underground storage facility. The individual cases for analysis are given in Table A-2.

TABLE A-1

CASES CONSIDERED FOR TIME AND MOTION ANALYSIS

Underground

1. Storage Room Forklift Operator
 - a. Dose from stack
 - b. Dose from waste being carried
 - c. Dose from pallet
2. Transporter Operator
 - a. Dose from pallet

Aboveground

3. Shipping Container Unloading Forklift Operator
 - a. Dose from container stack
 - b. Dose from waste being carried
 - c. Dose from pallet(s)
 - d. Dose from surge area
 4. Pallet Shuttle Forklift Operator
 - a. Dose from pallet (pallets in staging area)
 - b. Dose from pallet being carried
 - c. Dose from surge storage area
-

TABLE A-2

TIME AND MOTION ANALYSIS CASES

<u>Case No.</u>	<u>Description</u>
1.1	Underground storage room forklift operator, handling individual drums, 32-ft-wide room
1.2	Underground storage room forklift operator, handling six-packs or modular steel boxes, 32-ft-wide room
1.3	Underground storage room forklift operator, handling six-packs or modular steel boxes, 45-ft-wide room
2.1	Underground pallet transporter operator, 32-ft-wide room
2.2	Underground pallet transporter operator, 45-ft-wide room
3.1	Aboveground shipping container forklift operator (Title I, scheme #1), unloading individual drums
3.2	Aboveground shipping container forklift operator, (Title I, scheme #1), unloading six-pack or modular steel boxes
3.3	Aboveground shipping container forklift operator, (Sandia Concept), unloading six-packs or modular steel boxes
4	Aboveground pallet shuttle forklift operator

For the underground operations, two individuals will be in the vicinity of the low-level waste for significant portions of time. These are the forklift operator and the transporter operator. The sequence of operations in the underground facility is illustrated by Figure A-1² and outlined in Table A-3.^{3,4,5,6}

For the aboveground (surface facility) operations, two separate operations are analyzed: (1) forklift unloading of the incoming shipping containers on railcars and trucks; (2) forklift pallet handling from the staging area to the hoist area. The operations sequence is given by Table A-4.^{7,8} Should any of the shipments arrive in a damaged condition with external contamination (leakage), they will be

Figure A-1. Mechanical flow diagram.

TABLE A-3

SEQUENCE OF OPERATIONS
FOR
ANALYSIS OF UNDERGROUND FACILITIES

-
1. Down-shaft arrival of loaded pallet every 28 minutes.³
 2. Loaded pallet placed on TRU waste transporters and carried approximately 3,600 ft to storage room.^{4,5,6}
 3. Transporter parks at a 300-ft storage room (for the 32-ft-wide room, he parks where crosscut intersects haulage drift; for the 45-ft-wide room, he enters room and parks 50 ft from stack face.
 4. Forklift operator attaches to load (drums or boxes) with appropriate coupler.*
 5. Forklift trams load to face of stack at end of storage room (average of 150 ft).
 6. Forklift operator positions and stacks load.
 7. Forklift operator trams back to pallet to repeat sequence.
 8. After pallet is unloaded (approximately 12 minutes), forklift operator trams out of storage room and waits for next pallet in an area of minimal exposure such as the haulage drift.
 9. Transporter carries empty pallet back to hoist room.

* Pallet can contain one of four kinds of TRU waste containers:

- 1) individual 55-gal drums,
 - 2) six-pack of 55-gal drums,
 - 3) modular steel boxes, or
 - 4) steel overpacked boxes.
-

moved to the overpack and repair room before eventually being returned to the normal process flow of transport to the underground storage rooms. After decontamination and overpacking, the waste packages will be palletized, moved to the pallet load area, inventoried and then entered in the normal process flow. The postulated frequency of abnormal containers is low (estimated to be less than 2%);³ therefore, its impact on the forklift handling operations will be sufficiently small to neglect it for the purposes of the present analysis.

TABLE A-4

SEQUENCE OF NORMAL OPERATIONS FOR ANALYSIS OF
ABOVEGROUND FACILITIES

-
1. TRU waste arrives in special shipping containers via trucks or rail cars.
 2. The shipping containers are off-loaded and carried to the CH handling area via a bridge crane.
 3. A ramp is placed into the open end of the shipping container for unloading.
 4. A forklift then unloads the TRU waste from the shipping container and stacks it (drums or modular steel boxes) in a single level on the transport pallets.^{7,8}
 5. The pallet shuttle forklift (15-ton capacity) trams the full pallets to the pallet transfer car, where they are stacked two-high, in the CH airlock to be lowered by the hoist to the storage level (approximately 2,150 ft below the surface).^{7,8}
 6. If the CH airlock is momentarily full, the shuttle forklift places the loaded pallets in the surge storage area.
 7. The pallet shuttle forklift periodically removes and relocates empty pallets that have been hoisted up from the storage level.
 8. Any shipping containers that are contaminated from leaking barrels or boxes are handled in the overpack and repair room. This is anticipated to be an infrequent occurrence; consequently, it will have an insignificant impact on the normal operational flow of waste and is not considered in the time and motion analysis.
-

If the cycle in Table A-3 is interrupted, the surge area provides space for the palletized storage receipt of waste packages during a two-shift period. This area also stores the inventory of unused pallets.

The six-pack and the modular steel box are illustrated in Figures A-2 and A-3, respectively.

Figure A-2. 55-gal drum six-pack.

Figure A-3. Modular steel box.

A.1.1 Process Flow Rates

The CH waste flow (storage) rates are planned to be⁴

	<u>Volume/year</u> <u>ft³</u>
1st year	80,000
2nd year	130,000
3rd year	200,000
4th to 13th year	500,000
14th to 17th year	130,000
18th year	<u>50,000</u>
Total	5,980,000

The design goal flow rate of 500,000 ft³ per year (starting with year four) was used as the basis for this operations analysis and the operator dose calculations.

For the assumed one-shift-per-day operation, the planned number of shipments received are⁹

	<u>Truck</u>	<u>Railcar</u>
1 year	625	730
1 day	2.5	2.92

The CH waste is planned to arrive packaged as either individual or six-packed 55-gal drums (6 ft³ net volume), modular steel boxes (64 ft³ net volume), or in overpacked FRP RFP boxes (85 ft³ net volume). Eighty percent of the containers is planned to be drums. For the purposes of this study, a mixture of 80% drums and 20% modular steel boxes was assumed to be a realistic model for the T&M analysis.

One concept is for the drums to be banded together into six-packs for more efficient handling. The principal type of box container will be the modular steel box.

The specifications on these container systems are⁴

<u>Unit</u>	<u>Length</u>	<u>Width</u>	<u>Height</u>	<u>Waste Vol (ft³)</u>
Six-pack	73.5 in.	49.25 in.	36.0 in.	36.0
Modular steel box	74.0 in.	50.0 in.	37.5 in.	64.0

The drums (either individually or in six-packs) and the modular steel boxes will be transported to the storage room on pallets. These 12.5 by 8.5 ft pallets hold 24 drums or 4 six-packs or boxes as shown in Figure A-4.¹⁰

The design flow rate (based upon only drums) is 250 drums per day via railcar and 83 drums per day via truck; that is, a total of 333 drums per day. At 6 ft³ per drum and a 250-working-day year, this equates to the design goal of 500,000 ft³ per year.

For 80% of the containers to be drums, the flow rates compute to be

38.5 six-packs/day
9.63 pallets of drums/day

For the 20% modular steel boxes, the flow rates compute to be

9.62 boxes/day
2.4 pallets of boxes/day

These two types of waste containers combined require 12 pallets per day, on the average. The design flow rate (based upon individual drums at 333 drums per day) for pallet handling is 14 pallets per day, to be lowered on the hoist at 2 full pallets per trip. For this design flow rate, five trips are planned without empty pallet return and two trips are planned to return with empty pallets. When the cycle times for these seven trips are averaged, the mean value is 27.5 minutes per hoist cycle. This is the derivation of the 28 minutes shown in Table A-3.

This is summarized as

<u>No. of Trips</u>	<u>Cycle Time (min)</u>	<u>Hoist Usage Time (min)</u>	
		<u>100% Efficiency</u>	<u>80% Efficiency</u>
5	21	105	131
2	44	88	110
One Inspection Run		<u>30</u>	<u>38</u>
Total Hoist Usage Time/Shift		233	279

It is obvious that the design flow rates are higher than the actual expected rates for the 80/20 drum/box mixture, in order to meet the stored waste goal of 500,000 ft³ per year. A realistic operator dose calculation must use realistic long-term average rates. Therefore, the T&R analysis is based upon 12 pallets/day that carry an average of 231 drums plus 9-2/3 boxes.

A.1.2 General Assumptions

As with any analysis, clarifying or simplifying assumptions are necessary. Some general assumptions are highlighted as follows:

- The operators perform their tasks along prescribed routes, without deviating or taking a break until the task is finished; that is, an entire pallet unloaded.
- Constant velocities are used for all phases of vehicle motion.
- Plant operating factor is 0.8 (plant operating factor is a factor used to account for start-up times, shutdown times, personnel breaks, etc.).⁹
- The unloading of shipping containers from trucks and railcars is treated as one and the same process for the T&M analysis.

- There is one 8-hour shift per day operation.
- There are 250 working days per year.⁹
- Very few contaminated or leaking waste containers arrive at the facility; therefore, the analysis only considers normal operations.
- Essentially all the CH waste is in either the 55-gal drums (80%) and the modular steel boxes (20%).⁴
- Average flow rates leading to the storage goal of 500,000 ft³ per year are more appropriate for the T&M analyses than are the higher system design flow rates that are conservatively based upon peak conditions and handling only individual drums.
- The forklift operators and the radioactive sources are assumed to be at equal heights.
- Fourteen pallets per day are used for the individual drum handling cases.
- Twelve pallets per day are used for the six-pack and modular-steel-box handling cases.

A.2.0 TIME AND MOTION ANALYSES

A.2.1 Underground Storage Forklift Operator

Even though this is essentially the final operation in the storage sequence, a prior estimate placed the storage room forklift operator in the most exposed situation.¹¹ Therefore, this case is analyzed first. Three subcases are analyzed as (1) individual drum unloading in the present design configuration of a 32-ft-wide room (Case 1.1), (2) six-pack unloading in the 32-ft-wide room (Case 1.2), and (3) six-pack unloading in a 45-ft-wide room (Case 1.3).

The TRU waste tunnel complex and storage room operations are illustrated in Figures A-5 and A-6.^{4,12} The motion models show the relative distances from the forklift operator to the three sources of radiation exposure. The sources are (1) the carried drums or boxes, (2) the pallet, (3) the stack of drums and/or boxes. The exposure distances are defined more precisely as:

D1 = distance from operator center line to center line of forklift load (ft).

D2 = distance from operator center line to nominal face of pallet (ft).

D3 = distance from operator center line to nominal face of stack (ft).

A.2.1.1 Case 1.1: Underground Storage Forklift Operator, Individual Drums, 32-Ft-Wide Room

As illustrated in the motion model, Figure A-7, the room is too narrow for the transporter to enter and turn around; therefore, it parks in the intersection of the crosscut (storage room) and the haulage drift.

Figure A-6. Storage room forklift operations.

Figure A-7. T&M model; underground storage room, individual drums, 32 foot wide room.

A.2.1.1.1 Time Estimates for Case 1.1

The time estimates for Case 1.1 operations are as follows:

<u>Operation</u>		<u>Elapsed Time</u> (Assumes 80% Efficiency Factor)
Step 1	Position at pallet, engage or clamp onto drums and lift off pallet	29 sec
Step 2	Back up and turn 180 degrees	16 sec
Step 3	Tram from pallet to stack, an average of 150 ft at 5 ft/s	30 sec
Step 4	Position drums at the stack, lift into place and unload.	54 sec
Step 5	Back up and turn 180 degrees.	16 sec
Step 6	Tram back to the pallet.	<u>30 sec</u>
Total time per cycle		175 sec

A.2.1.1.2 Assumptions

- For drums only, the objective of storing 500,000 ft³/yr (net waste) means that 333 drums per day will be handled; this is 14 pallets per day.
- The pallet transporter parks at the entrance to the storage room; he does not enter because the room (32 ft wide) is too narrow for the transporter to turn around and exit.
- The forklift operations cycle time of 175 seconds is assumed to also represent the time for unloading the pallet from the front (facing the stack) as well as from the back (forklift cannot reach across the pallet to pick up container on the back side).

- The storage room is 300 ft long; therefore, the average tram from pallet to stack is 150 ft.⁴
- There will be enough slack time between pallet loads for forklift operator to change lifting attachments as required for the various waste containers.
- During slack time, the forklift operator will tram out of storage area and await next pallet while in the haulage drift, so he is outside the line-of-sight from the stack.
- The forklift moves at a constant velocity of 5 ft/s (as actually timed at Sandia Contact Handled Waste Demonstration Facility).

A.2.1.1.3 Results

The T&M analysis for this storage room forklift operator is derived from the times given above and the geometry illustrated in Figure A-7. The results are given by Table A-5.

If the drums are unloaded individually, 24 cycles will be required. This totals to 70 minutes per pallet. For the average daily total of 14 pallets, 16-1/3 hours of work is required. This would necessitate more than one forklift (probably working in adjacent storage rooms).

A.2.1.2 Case 1.2: Underground Storage Forklift Operator, Six-Pack Handling, 32-Ft-Wide Room

Figure A-8 illustrates the motion model used for this case which is very similar to Case 1.1 except for the load carried. Consequently there is 1/6th as many trams between the stack and the pallet.

TABLE A-5

TIME AND MOTION: UNDERGROUND STORAGE, FORK LIFT OPERATOR, 32-FT-WIDE-ROOM, CASES 1.1, 1.2

		Time (seconds)														
		0	45	50	55	60	65	70	75	145	150	155	160	165	170	175
Distance to Sources* (ft)	D1	6														
	D2	8														
	D3	150														
	D1		6	6	6	6	6	6								
	D2		16	38	62	88	112	134								
	D3		134	112	88	62	38	16								
	D1								6							
	D2								150							
	D3								8							
	D1															
	D2										134	112	88	62	38	16
	D3										16	38	62	88	112	134
	Positioning at Pallet and Engaging load		Tram 150 ft from pallet to stack							Positioning Near Stack		Return Tram 150 ft to Pallet				
	Start of Cycle															End of Cycle

*Note: Operator-to-Source Distances D1, D2, D3
Defined in Figure A-8

Figure A-8. T&M model; underground storage room.

A.2.1.2.1 Time Estimates for Case 1.2

The time estimates for Case 1.2 operations are the same as those used for Case 1.1.

A.2.1.2.2 Assumptions

- Assumptions for Case 1.1 apply.
- The forklift operations cycle time of 175 seconds for individual drums is also assumed to represent an average time for six-packs or boxes.

A.2.1.2.3 Results

The T&M analysis for a single cycle for Case 1.2 is identical to that for Case 1.1; that is, the results are given by Table A-5.

According to the time estimates in Table A-5, four cycles will conservatively require slightly less than 12 minutes; therefore, there are 21 minutes of slack time per pallet. For the average total of 12 pallets per shift day, the storage room operator will perform 48 cycles (as in Table A-5) per day. If an hour of time is used for startup, shutdown, cleanup, etc., there remain 7 hours or about 35 minutes per pallet for unloading. The unloading requires about 2-1/3 hours of work; the remaining 4-2/3 hours will not need to be spent in the radiation exposure area and will thus not be considered to add to the operator's accumulated dose.

A.2.1.3 Case 1.3: Underground Storage Forklift Operator, Six-Pack Handling, 45-Ft-Wide Room

A currently considered alternative is to make the crosscut storage rooms 45 ft wide. This will allow the transporter vehicle to enter the room and drive to within about 50 ft of the current stack face to shorten the forklift tram distance. After the pallet is unloaded, the

transporter has sufficient space to complete a turn and exit the storage room.

Figure A-9 illustrates the motion model for this case. Note that there is now space for an extra row of six-pack containers.

A.2.1.3.1 Time Estimates for Case 1.3

The time estimates for Case 1.3 operations are as follows:

	<u>Operation</u>	<u>Elapsed Time (Assumes 80% Efficiency Factor)</u>
Step 1	Position at pallet, engage or clamp onto drums and lift off pallet	29 sec
Step 2	Back up and turn 180 degrees	16 sec
Step 3	Tram from pallet to stack, an average of 50 ft at 5 f/s	8 sec
Step 4	Position drums at the stack, lift into place and unload	54 sec
Step 5	Back up and turn 180 degrees	16 sec
Step 6	Tram back to the pallet	<u>8 sec</u>
	Total time per cycle	131 sec

A.2.1.3.2 Assumptions

- The pallet transporter enters the 45-ft-wide storage room and parks 50 ft from the stack face.
- The forklift operations cycle time of 131 seconds is assumed to apply to boxes as well as to six-packs.
- Other assumptions from Case 1.1 apply.

Figure A-9. T&M model; underground storage room, six-pack loading, 45 foot wide room.

A.2.1.3.3 Results

The T&M analysis for this storage room forklift operation is derived from the times given above and the geometry illustrated in Figure A-9. The results are given by Table A-6.

The four cycles to unload a pallet will require 8-3/4 minutes. For the daily average of 12 pallets, the forklift operator will only need to work a total of 1-3/4 hours. The remaining time is assumed to be outside the line-of-sight exposure and is not considered to add to the accumulated dose.

TABLE A-6

TIME AND MOTION: UNDERGROUND STORAGE, FORKLIFT OPERATOR, 45-FT-WIDE-ROOM, CASE 1.3

		Time (seconds)							
		0	45	50	55		125	130	135
Distance to Sources* (ft.)	D1 D2 D3	6 8 50							
	D1 D2 D3		6 20 30	6 40 10					
	D1 D2 D3				6 42 8				
	D1 D2 D3					25 25			
		Positioning at pallet and engaging load	Tram 42 ft pallet to stack	Positioning near stack		Return tram			
	Start of Cycle							End of Cycle	

*Note: Operator-to-Source Distances D1, D2, D3
Defined in Figure A-8.

A.2.2 Underground Pallet Transporter Operator

This T&M analysis involved the exposure to the driver and/or helper of the CH waste transporter. This special truck transports a loaded pallet from the hoist off-load station to the storage room entrance and then returns an empty pallet for the hoist to carry to the surface for a repeat of the cycle.

A.2.2.1 Case 2.1: Underground Transporter Operator, 32-ft-Wide Room

The only radiation exposure source considered pertinent to this case is the loaded pallet. Its proximity to the crew cab is shown in Figure A-10. If the transporter operator parks across from the entrance to the storage room, he will receive a radiation dose from the storage room stack. In order to allow the future computation of the total dose to a single operator for both the transporter and the storage room forklift, the two doses must be independent. Therefore, it is assumed that the transporter operator parks so that the cab is past the storage room entrance (as shown in Figure A-6) so that he does not have line-of-sight exposure to the stack.

Figure A-10. Loaded pallet on CH waste transporter.

A.2.2.1.1 Time Estimates for Case 2.1 Transporter Operation

Based upon estimated travel distances in the repository tunnel complex, average distances from the hoist (TRU shaft) to a working storage room will be about 3,660 ft. The estimated straight-away speed of the pallet transporter is 10 mph.

In this case, 4 minutes 9-1/2 seconds would be used for tram time if the transporter traveled in a straight line. If the 80% efficiency factor were applied, this time would be somewhat greater than 5 minutes. Taking into account four 90-degree turns, deceleration and stopping time, an additional 48 seconds was added for a total tram time from TRU shaft to stacked TRU waste storage room, for a total of 6 minutes.⁶

The remaining exposure time occurs during the pallet unloading-reloading operation. The net results are summarized as:

6 minutes--one way trip

11 minutes--unload and reload pallets (maximum)

17 minutes--worst case exposure time

A.2.2.1.2 Assumptions

- An average travel distance for year four (the first year to reach the design goal of 500,000 ft³ of waste storage) is representative of subsequent years (an error in this estimate is not critical).
- The straight-away speed is a constant 10 mph.
- The average-day quantity of 12 pallets is used.
- The transporter operator is assumed to wait in a location away from the radiation effects of the storage room stack while the pallet is being unloaded by the forklift.
- The only significant exposures occur from the pallet during (1) loading, (2) transporting, (3) unloading.

A.2.2.1.3 Results

When the transporter is carrying a loaded pallet, the front face of the waste container is 12.75 ft behind and 2.7 ft below the center line

of the operator.¹³ Therefore, the exposure is a constant dose at a slant range of 13 ft for 17 minutes per pallet or 204 minutes per 8-hour shift.

A.2.2.2 Case 2.2: Underground Transporter Operator, 45-Ft-Wide Room

In this instance, the transporter enters the storage room, parks 50 ft from the stack face, waits while the forklift unloads the pallet, then exits the room and returns to the hoist off-load station for another pallet loaded with waste containers. This case has the radiation exposure from the transported pallet as in Case 2.1. In addition, the operator is exposed to (1) the storage room stacked waste while he waits for the forklift to unload the pallet, and (2) a partially emptied pallet sitting on the transporter.

A.2.2.2.1 Time Estimates for Case 2.2 Transporter Operation

The time estimates for the pallet exposure during transport are the same as for Case 2.1; that is, 17 minutes. The exposure from the stack is taken from Case 1.3 where about 9 minutes are required to unload four six-packs or boxes from the pallet. The exposure from the pallet being emptied is taken as a full pallet for half the total unloading time, i.e., a full pallet for about 4-1/2 minutes.

A.2.2.2.2 Assumptions

- The pallet is assumed to contain four six-packs or boxes, rather than 24 individual drums.
- Radiation exposure from the pallet being emptied can be represented by a full pallet for half the total unloading time.
- Other assumptions are as previously stated for Case 2.1.

A.2.2.2.3 Results

The transporter operator is exposed to (1) a loaded pallet at a constant slant range of 13 ft for 17 minutes per trip, (2) the storage room stack face at a distance of 50 ft for 9 minutes per trip, and (3) a loaded pallet at a slant range of 13 ft for 4-1/2 minutes as the pallet is unloaded each trip. These two exposures will total to 204 and 108 and 54 minutes per 8-hour shift, respectively.

A.2.3 Aboveground Shipping Container Forklift Operator

Figure A-11 shows the floor plan for the aboveground waste handling; this should be used to clarify both the shipping container unloading and the pallet handling.

The motion models in Figures A-12 and A-13 show the relative distances from the forklift to the various radiation sources. The sources are (1) the carried drums or boxes, (2) the pallets, (3) the shipping container. The exposure distances are defined more precisely as:

- D1 = distance from operator center line to nearest face of forklift load (ft).
- D2 = distance from operator center line to nearest face of waste containers on the pallet being loaded (ft).
- D3 = distance from operator center line to nominal face of waste stack in shipping container being unloaded (ft).
- D4 = distance from operator center line to nearest face of waste containers on adjacent full pallet (ft).
- D5 = distance from operator center line to nominal face of full surge storage area (ft).

Figure A-12 illustrates the radiation exposure geometry when the operator is adding drums to the near side of one pallet while a second full pallet is waiting to be picked up by the 15-ton pallet shuttle forklift.¹⁴ The average state of the shipping container will be half full; therefore, the operator's line-of-sight dose is measured from the stack face halfway into the shipping container.

Figure A-11. Aboveground CH handling (Title 1), plan view.

Figure A-12. T&M model; aboveground shipping container unloading to pallet near side.

Figure A-13. T&M model; aboveground shipping container unloading to pallet far side.

Figure A-13 is the companion to the previous figure and illustrates the alternate case of the operator's motion swinging around to load the far side of the nearly filled pallet. He is also exposed to a second full pallet waiting to be trammed to the hoist cage.

The time estimates for the forklift operations between the shipping containers and the near side pallets are as follows:

	<u>Operation</u>	<u>Elapsed Time</u> (Assumes 80% Efficiency Factor)
Step 1	Position forklift at shipping container, engage or close up onto drums and lift	29 sec
Step 2	Back down ramp and turn 180 degrees	16 sec
Step 3	Tram to pallet near side, an average of 8 ft at 2.5 ft/s	4 sec
Step 4	Position forklift at pallet, lift into place and and unload	32 sec
Step 5	Back up and turn 180 degrees	16 sec
Step 6	Tram from near side and up ramp into shipping container, an average of 22.5 ft at 2.5 ft/s	9 sec
	Total time per cycle	106 sec

A.2.3.1

Time Estimates for Cases 3.1 and 3.2 Shipping Containers Forklift Unloading Operations (Title I)

The time estimates for the forklift operations between the shipping containers and the far side pallets are as follows:

	<u>Operation</u>	<u>Elapsed Time</u> (Assumes 80% Efficiency Factor)
Step 1	Position forklift at shipping container, engage or close up onto drums and lift	29 sec
Step 2	Back down ramp and turn 180 degrees	16 sec

	<u>Operation</u>	<u>Elapsed Time (Assumes 80% Efficiency Factor)</u>
Step 3	Tram to pallet far side, an average of 63 ft at 3 ft/s	21 sec
Step 4	Position forklift at pallet, lift into place and and unload	32 sec
Step 5	Back up	5 sec
Step 6	Tram from far side and up ramp into shipping container, an average of 78 ft at 3 ft/s	<u>26 sec</u>
	Total time per cycle	129 sec

The process flow will alternate between loading the pallets from the near side and from the far side; therefore an average cycle time of 118 seconds is appropriate and will be used in the analysis to follow.

A.2.3.1.1 Assumptions

- The shipping containers on the railcars are carried to the laydown area, via a bridge crane, for inspection and unloading by forklift.
- The shipping containers on the flatbed trucks are docked in the laydown area and the forklift unloads them as they remain on the truck.
- Forklift operations times are average and include an 80% efficiency factor.
- CH waste arrives in loose 55-gal drums³ and modular steel boxes.
- The time and motion for unloading the containers that arrive by truck can be represented by the T&M computed for the containers from the railcars. The differences are anticipated to be slight, and use of the data from the railcar case is judged to be a conservative approximation of the truck case.

- The shipping container was assumed to be half-unloaded for average conditions of this analysis.
- Only two pallets were assumed to be significant radiation sources for this forklift driver. One pallet was full and awaiting removal by the 15-ton forklift and the second pallet was the one the operator was currently filling.
- Two basic geometries (Figures A-12 and A-13) adequately represent the significant radiation exposure scenarios for the shipping container unloading. Each of these two are applicable half the time.

A.2.3.1.2 Results: Title I Concept, Cases 3.1 and 3.2

The T&M analysis for the Title I conceptual operations considers the handling of individual drums, modular steel boxes, and six-packs. Handling of the boxes is considered to be equivalent to handling the six-packs.

The T&M analysis for the aboveground forklift operator who unloads the individual drums from the shipping containers is derived from the times given previously and the geometry illustrated in Figures A-12 and A-13. Half the time the operator is placing the drums on the near side of the pallet and half the time he is placing the drums on the far side of the pallet.

As in the case of the underground operators, the analysis is based upon the long-term average of handling 12 pallets per day (9.63 pallets of drums and 2.4 pallets of boxes).

Table A-7 summarizes the results of the time-dependent slant range computations for near side pallet loading and Table A-8 summarizes the results for loading drums out the far side of the pallet.

TABLE A-2

TIME AND MOTION: ABOVEGROUND SHIPPING CONTAINER FORKLIFT OPERATOR: NEAR SIDE STACKING

[illegible]

*Note: Operator-to-Source Distances D1, D2, D1, D4, D5 Defined in figure A-12

TABLE A-8

TIME AND MOTION: ABOVEGROUND SHIPPING CONTAINER FORKLIFT OPERATOR: FAR SIDE STACKING

[illegible]

*Note: Operator-to-Source Distances D1, D2, D3, D4, D5 Defined in figure A-11

The estimated cycle time for loading the near side of the pallet is 106 seconds and, conversely, 129 seconds are needed to load the far side of the pallet. The previously published rate (SK-41-F-004 and SK-41-F-005, Revision 4/11/79, of Reference 3) for shipping container unloading was 165 seconds per cycle as compared to the 118 used in the present study.

Case 3.1: Individual Drum Unloading

If only the handling of individual drums is considered, and the average cycle time is 118 seconds, a total of about 10.9 forklift-hours is required to unload and handle the average daily influx of 333 drums.

Case 3.2: Six-Pack and Box Unloading

The average cycle time of 118 seconds also applies to the handling of six-packs and boxes. However fewer trips are required to unload shipping containers filled with six-packs or boxes. A total of about 1-1/4 hours is required to unload six-packs to fill 9.63 pallets per day, and 0.3 hours are needed to unload boxes for the remaining 2.4 pallets per day.

A.2.3.2 Time Estimates for Case 3.3: Shipping Containers Forklift Unloading Operations (Sandia Version 9/78)

The geometry for this scenario is illustrated by Figure A-14. This shows a single, small forklift performing the complete unloading operation from shipping container to the pallet transfer car in the CH airlock.

The previous 80/20 mix of drums (in six-packs) and modular steel boxes is assumed for this more streamlined handling case. The time estimates for the forklift to unload the waste containers from the TRU-PACT shipping containers and tram them directly to the transfer car staging pallets are as follows:

Figure A-14. T&M model; aboveground shipping container unloading (Sandia Version).

	<u>Operation</u>	<u>Elapsed Time</u> (Assumes 80% Efficiency Factor)
Step 1	Position forklift at shipping container, engage and lift six-pack or box	29 sec
Step 2	Back down ramp and turn 90 degrees	14 sec
Step 3	Tram to pallet in transfer car staging area, an average of 90 ft at 5 ft/s	18 sec
Step 4	Position forklift at pallet, lift six-pack into place and unload	32 sec
Step 5	Back up and turn 180 degrees	16 sec
Step 6	Return tram and turn into shipping container ramp, average of 100 ft at 5 ft/s	<u>20 sec</u>

Total time per cycle 129 sec

A.2.2.2.1 Assumptions

- An 80/20 split of six-packed drums and modular steel boxes is assumed.
- Six-packs and modular steel boxes arrive in the TRU-PACT shipping containers (via truck and railcar) stacked two-high and four-deep.
- Forklift operations times are average and include an 80% efficiency factor.
- The surge storage area is assumed to be full, for a worst-case exposure analysis.
- The pallets in the transfer car staging area are assumed to be full.

- The forklift picks up the six-packs at the shipping container doorway and is not required to enter.

A.2.3.2.2 Results--Case 3.3: Sandia Version 9/79

Table A-9 summarizes the results of the T&M computations of operator-to-source slant ranges.

An estimated 129 seconds are required to complete a waste container handling cycle from shipping container to pallet and return. The number of cycles required to process the average day's ingress of waste is 48 cycles to fill 12 pallets. Therefore, the total accumulated forklift operation is about 1.7 hours per day. This applies to any configuration of six-packs and modular steel boxes, since their handling cycle times are estimated to be the same.

A.2.3.3 Time Estimates for Case 4: the Pallet Shuttle Forklift Operations

The geometry for this case is illustrated in Figure A-15. Here the 15-ton forklift trams fully loaded pallets from the pallet staging area to the pallet transfer car in the CH airlock.

The time estimates for the large, 15-ton forklift that shuttles the pallets between the pallet staging area and the waste hoist area are as follows:

	<u>Operation</u>	<u>Elapsed Time (Assumes 80% Efficiency Factor)</u>
Step 1	Position forklift to engage pallet, engage and lift	29 sec
Step 2	Back up 20 ft and turn 90 degrees	18 sec
Step 3	Tram to pallet transfer car, an average of 110 ft at 5 ft/s	22 sec

A-45

*Note: Operator-to-Source Distances D1, D2, D3, D4 Defined in Figure A-14

A-45

Figure A-15. T&M model; aboveground shipping container unloading; pallet shuttle.

	<u>Operation</u>	<u>Elapsed Time (Assumes 80% Efficiency Factor)</u>
Step 4	Position forklift and unload pallet on pallet transfer car	32 sec
Step 5	Back up 32 ft and turn 90 degrees at 2.5 ft/s	22 sec
Step 6	Tram to next pallet in staging area, an average of 105 ft at 5 ft/s	<u>21 sec</u>
	Total time per cycle	144 sec

A.2.3.3.1 Assumptions

- The only significant radiation exposure sources for the forklift operator are a full pallet staging area, the single pallet being transported, and a full surge storage area.
- The 80/20 mixture of drums and boxes is assumed; therefore, the average daily ingress of waste containers will be handled on 12 pallets.

A.2.3.3.2 Results: Case 4

The forklift operator is exposed to radiation from three significant sources: 1) the pallet staging area; 2) the pallet being transported; and 3) the surge storage area. Table A-10 summarizes the T&M computations.

It takes an estimated 144 seconds to unload and handle each pallet. The number of pallets to be transferred to the hoist cage on an average day is only 12; therefore, the total forklift operation time will be only about 1/2 hour per day. The previously published rate (SK-41-F-004 and SK-41-F-005, Revision 9/11/79, Reference 3) for pallet handling is 180 seconds per cycle as compared to the 144 seconds used in the present analysis.

TIME AND MOTION: ABOVEGROUND PALLET SHUTTLE FORKLIFT OPERATOR

End
of
Cycle

*Note: Operator-to-Source Distances D1, D2, D3, Defined in Figure A-15

APPENDIX A REFERENCES

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APPENDIX B
DOSE RATES FOR SOURCE CONTAINERS

APPENDIX B

DOSE RATES FOR SOURCE CONTAINERS

The information for waste container characteristics and sources is taken from a previous LATA report (LATA No. 72) and the WIPP Title I "Design Basis Report for Radiological Protection." In order to check the accuracy of the previously used analytical methods, Monte Carlo calculations were performed for a single drum and for a stack of drums in the underground configuration. This appendix documents the comparison between the Monte Carlo and semianalytic methods.

B.1 Monte Carlo Calculations

The Monte Carlo code MCNP¹ was used to model photon transport in and about 55-gal light drums containing small quantities of weapons-grade plutonium. Tissue dose rates were computed at points exterior to a single drum and also at points exterior to a stack of drums.

The approach for these problems was to perform Monte Carlo calculations for each of seven isotopes found in weapons-grade plutonium. These isotopes are ²³⁷U, ²³⁸Pu, ²³⁹Pu, ²⁴⁰Pu, ²⁴¹Pu, ²⁴²Pu and ²⁴¹Am. Uranium-237 and ²⁴¹Am are both daughters of ²⁴¹Pu. Having performed the transport calculations for each isotope, one can then fold in the time dependence of the isotopic concentrations. In all calculations, it was assumed that the presence of the small quantities of the cited isotopes affected photon transport negligibly.

B.1.1 Source Characterization

An important part of these calculations was the characterization of the photon sources. Each of the isotopes cited previously releases discrete quanta of electromagnetic radiation (photons) as disintegration occurs. Several references were consulted before selection of one to obtain the photon source data. The library of decay photon intensities chosen (a German compilation)² was made available as a magnetic tape.

These data are given as absolute and relative photon line intensities. Literally hundreds of individual lines are listed for the isotopes in question. After evaluation of the data, an energy bin structure was selected for use in the Monte Carlo calculations. A 90-bin structure from 0 to 0.9 MeV was chosen with each bin 10 keV wide. An existing program was modified to process the line data into the bin structure for each of the isotopes in question. The binned photon data used in the Monte Carlo calculations are shown in Table B-1. These finely binned source data are quite good characterizations of the real source energy distributions.

B.1.2 Geometry and Materials

The geometry used in the single-light-drum calculations is shown schematically in Figure B-1. Dose rates were calculated at three radial distances (5, 30 and 100 cm) from the drum surface in the mid-plane. Ring detectors³ were used in the calculations to enhance computing efficiency. The outside dimensions of the drum are shown in Figure B-1. The drum skin was modeled as iron at 7.86 g/cm^3 . The interior of the drum was modeled as carbon at 0.24 g/cm^3 . The iron thicknesses used were 0.0533 in. (top) and 0.0428 in. (bottom and body). These are minimum (rather than nominal) thicknesses for 16 and 18 gauge steels, respectively. Air at $1.293 \times 10^{-3} \text{ g/cm}^3$ was used outside the drum.

A schematic of the geometry used in the stack calculations is shown in Figure B-2. The large flat cylinder models the first layer of a larger drum array, and is equivalent to approximately 11 drums. The cylinder diameter corresponds to three drum heights while the thickness of the flat cylinder corresponds to one drum diameter. The large flat cylinder is actually a sandwich. The top and bottom were modeled as iron (one-drum-side thickness each) while the middle layer was again modeled as carbon. This idealized geometry, while quite simple, models the photon transport quite well. The Monte Carlo calculations on the single light drum showed that one drum thickness represents over five average track mean free paths for ^{241}Am photons (as will become evident, ^{241}Am is by far the most important isotope). Therefore, one layer of

TABLE B-1

PHOTONS PER DISINTEGRATION IN 90 ENERGY BINS

Bio	^{237}U	^{238}Pu	^{239}Pu	^{240}Pu	^{241}Pu	^{242}Pu	^{241}Am
1	0.	0.	0.	0.	0.	0.	0.
2	0.	0.	7.00×10^{-3}	0.	0.	0.	0.
3	2.40×10^{-2}	1.30×10^{-1}	9.00×10^{-4}	0.	0.	0.	2.50×10^{-2}
4	0.	0.	8.80×10^{-5}	0.	1.00×10^{-7}	0.	2.00×10^{-3}
5	0.	3.80×10^{-4}	2.70×10^{-4}	1.00×10^{-4}	5.00×10^{-7}	4.20×10^{-4}	7.00×10^{-4}
6	3.56×10^{-1}	0.	2.38×10^{-4}	0.	3.00×10^{-7}	0.	3.53×10^{-1}
7	1.30×10^{-2}	0.	7.70×10^{-6}	0.	0.	0.	0.
8	0.	0.	2.10×10^{-6}	0.	1.20×10^{-6}	0.	0.
9	0.	0.	1.00×10^{-7}	0.	0.	0.	0.
10	1.75×10^{-1}	9.36×10^{-5}	1.50×10^{-4}	0.	3.40×10^{-5}	0.	2.92×10^{-4}
11	2.73×10^{-1}	0.	2.60×10^{-6}	1.00×10^{-4}	1.10×10^{-6}	9.10×10^{-5}	3.34×10^{-4}
12	1.33×10^{-1}	5.00×10^{-7}	7.48×10^{-5}	0.	1.17×10^{-5}	0.	2.20×10^{-1}
13	0.	1.00×10^{-7}	5.73×10^{-5}	0.	1.00×10^{-7}	0.	8.10×10^{-1}
14	0.	0.	0.	0.	0.	0.	1.00×10^{-1}
15	0.	0.	2.30×10^{-6}	0.	2.20×10^{-6}	0.	8.00×10^{-1}
16	0.	1.31×10^{-5}	1.00×10^{-7}	0.	1.00×10^{-7}	5.30×10^{-6}	1.60×10^{-6}
17	2.10×10^{-2}	0.	1.30×10^{-6}	6.90×10^{-6}	0.	0.	4.90×10^{-6}
18	0.	0.	1.40×10^{-6}	0.	0.	0.	4.00×10^{-7}
19	0.	0.	9.00×10^{-7}	0.	0.	0.	0.
20	0.	2.00×10^{-7}	1.00×10^{-6}	0.	0.	0.	6.00×10^{-7}
21	2.34×10^{-1}	2.00×10^{-7}	4.90×10^{-6}	0.	0.	0.	1.61×10^{-5}
22	0.	0.	0.	0.	0.	0.	0.
23	2.00×10^{-4}	0.	1.03×10^{-7}	0.	0.	0.	1.00×10^{-6}
24	3.00×10^{-4}	0.	2.00×10^{-7}	0.	0.	0.	1.00×10^{-7}
25	0.	0.	5.00×10^{-7}	0.	0.	0.	5.00×10^{-7}
26	0.	1.00×10^{-7}	8.00×10^{-7}	0.	0.	0.	0.
27	8.60×10^{-3}	0.	3.00×10^{-7}	0.	0.	0.	9.00×10^{-7}
28	0.	0.	0.	0.	0.	0.	2.00×10^{-7}
29	0.	0.	0.	0.	0.	0.	0.
30	3.00×10^{-5}	0.	4.00×10^{-7}	0.	0.	0.	8.00×10^{-7}
31	0.	0.	2.00×10^{-7}	0.	0.	0.	2.00×10^{-7}
32	0.	0.	3.00×10^{-7}	0.	0.	0.	1.30×10^{-6}
33	0.	0.	9.00×10^{-7}	0.	0.	0.	3.30×10^{-6}
34	1.41×10^{-2}	1.00×10^{-7}	5.20×10^{-6}	0.	0.	0.	1.45×10^{-5}
35	0.	0.	5.60×10^{-6}	0.	0.	0.	3.00×10^{-7}
36	0.	1.00×10^{-7}	1.00×10^{-7}	0.	0.	0.	2.00×10^{-7}
37	5.00×10^{-4}	0.	1.70×10^{-6}	0.	0.	0.	4.80×10^{-6}
38	1.20×10^{-3}	0.	1.51×10^{-5}	0.	0.	0.	4.20×10^{-6}
39	0.	0.	5.50×10^{-6}	0.	0.	0.	6.00×10^{-7}
40	0.	0.	5.50×10^{-6}	0.	0.	0.	2.00×10^{-7}
41	0.	0.	0.	0.	0.	0.	0.
42	0.	1.00×10^{-7}	1.51×10^{-5}	0.	0.	0.	4.00×10^{-7}
43	0.	0.	1.50×10^{-6}	0.	0.	0.	5.00×10^{-7}
44	0.	1.00×10^{-7}	1.00×10^{-7}	0.	0.	0.	2.00×10^{-7}
45	0.	0.	1.00×10^{-7}	0.	0.	0.	4.00×10^{-7}

TABLE B-1 (concluded)

PHOTONS PER DISINTEGRATION IN 90 ENERGY BINS

B-10	²³⁷ U	²³⁸ U	²³⁹ U	²⁴⁰ U	²⁴¹ U	²⁴² U	²⁴³ U
46	0.	0.	1.90×10^{-6}	0.	0.	0.	5.00×10^{-7}
47	0.	0.	1.00×10^{-7}	0.	0.	0.	0.
48	0.	0.	0.	0.	0.	0.	0.
49	0.	0.	1.00×10^{-7}	0.	0.	0.	0.
50	0.	0.	0.	0.	0.	0.	0.
51	0.	0.	0.	0.	0.	0.	0.
52	0.	0.	0.	0.	0.	0.	1.00×10^{-7}
53	0.	0.	0.	0.	0.	0.	8.00×10^{-7}
54	0.	0.	0.	0.	0.	0.	1.00×10^{-7}
55	0.	0.	0.	0.	0.	0.	1.00×10^{-7}
56	0.	0.	1.00×10^{-7}	0.	0.	0.	0.
57	0.	0.	0.	0.	0.	0.	1.00×10^{-7}
58	0.	0.	0.	0.	0.	0.	1.00×10^{-7}
59	0.	0.	0.	0.	0.	0.	0.
60	0.	0.	0.	0.	0.	0.	3.00×10^{-7}
61	0.	0.	0.	0.	0.	0.	0.
62	0.	0.	2.00×10^{-7}	0.	0.	0.	1.30×10^{-6}
63	0.	0.	0.	0.	0.	0.	0.
64	0.	0.	1.00×10^{-7}	0.	0.	0.	0.
65	0.	0.	2.00×10^{-7}	1.00×10^{-7}	0.	0.	2.00×10^{-7}
66	0.	0.	3.00×10^{-7}	0.	0.	0.	8.00×10^{-7}
67	0.	0.	0.	0.	0.	0.	7.80×10^{-7}
68	0.	0.	0.	0.	0.	0.	1.30×10^{-6}
69	0.	0.	0.	1.00×10^{-7}	0.	0.	7.00×10^{-7}
70	0.	0.	0.	0.	0.	0.	1.00×10^{-7}
71	0.	0.	1.00×10^{-7}	0.	0.	0.	2.00×10^{-7}
72	0.	0.	1.00×10^{-7}	0.	0.	0.	0.
73	0.	0.	0.	0.	0.	0.	4.20×10^{-6}
74	0.	0.	0.	0.	0.	0.	1.00×10^{-7}
75	0.	1.00×10^{-7}	0.	0.	0.	0.	0.
76	0.	0.	1.00×10^{-7}	0.	0.	0.	2.00×10^{-7}
77	0.	3.00×10^{-7}	1.00×10^{-7}	0.	0.	0.	1.00×10^{-7}
78	0.	0.	0.	0.	0.	0.	2.00×10^{-7}
79	0.	1.00×10^{-7}	0.	0.	0.	0.	2.00×10^{-7}
80	0.	0.	0.	0.	0.	0.	0.
81	0.	1.00×10^{-7}	0.	0.	0.	0.	1.00×10^{-7}
82	0.	1.00×10^{-7}	0.	0.	0.	0.	0.
83	0.	0.	0.	0.	0.	0.	0.
84	0.	0.	0.	0.	0.	0.	0.
85	0.	0.	0.	0.	0.	0.	0.
86	0.	1.00×10^{-7}	0.	0.	0.	0.	0.
87	0.	0.	0.	0.	0.	0.	1.00×10^{-7}
88	0.	0.	0.	0.	0.	0.	1.00×10^{-7}
89	0.	1.00×10^{-7}	0.	0.	0.	0.	0.
90	0.	0.	0.	0.	0.	0.	0.
Total	1.25×10^0	1.30×10^{-1}	8.60×10^{-3}	2.07×10^{-4}	5.13×10^{-5}	5.16×10^{-6}	3.81×10^{-1}

Figure B-1. Schematic of geometry for Monte Carlo calculations of single 55-gal drum (dimensions in cm).

Figure B-2. Schematic of geometry for Monte Carlo calculations of stack of 55-gal drums (dimensions in cm).

drum is sufficient for the calculations. In these stack calculations, point detector dose rates were computed at three distances (5, 100 and 500 cm) from the stack along the axis of the flat cylinder. As in the single drum calculations, air surrounded the mock stack.

B.1.3 Results and Conclusions

A total of 14 MCNP runs were made (one for each of the 7 isotopes times 2 geometries). These calculations included the effects of fluorescence. Photon fluxes were converted to tissue dose rates by using the data of Reference 4. The flux-to-dose-rate factors used in the calculations are shown in Table B-2. Note that the bin structure for the dose rate tallies differs from the source-energy structure. The MCNP code allows this flexibility. The calculations were normalized to yield mrem/hr per curie (3.7×10^{10} dis/s) of the subject isotope. The activity levels of the isotopes (in curies) as a function of time were taken from an ORIGEN calculation (described in Subsection B.2.1) for 1 gram of weapons-grade plutonium. These activities are given in Table B-3.

Results of the MCNP runs were folded appropriately with the activities of Table B-3 to yield dose rates versus time and distance from both the single drum and the stack of drums. Tables B-4 and B-5 display results obtained for the single drum and the stack, respectively. Statistical uncertainties in the Monte Carlo results averaged 2 and 5% for the single-drum and stack calculations, respectively.

The data from Table B-4 (single drum) at 100 cm are shown plotted in Figure B-3. The most important feature of this plot is the dominance of ^{241}Am in contributing to the total dose rate. The ^{241}Am activity peaks at 70 years and at that time accounts for 96% of the total dose rate. The corresponding percentage at zero time is 53%. The photons emitted in ^{241}Am decay are predominantly low in energy and would be easy to shield against, should that be a viable approach to operator protection.

TABLE B-2
PHOTON FLUX-TO-DOSE-RATE CONVERSION FACTORS

$$\frac{\text{mrem/hr}}{\text{photon/cm}^2/\text{s}}$$

Bin	E_{low} (MeV)	E_{high} (MeV)	Factor
1	0.01	0.02	2.1×10^{-3}
2	0.02	0.03	8.3×10^{-4}
3	0.03	0.04	4.5×10^{-4}
4	0.04	0.05	3.2×10^{-4}
5	0.05	0.06	2.8×10^{-4}
6	0.06	0.07	2.6×10^{-4}
7	0.07	0.08	2.6×10^{-4}
8	0.08	0.10	2.7×10^{-4}
9	0.10	0.15	3.3×10^{-4}
10	0.15	0.20	4.4×10^{-4}
11	0.20	0.25	5.7×10^{-4}
12	0.25	0.30	7.0×10^{-4}
13	0.30	0.35	8.2×10^{-4}
14	0.35	0.40	9.3×10^{-4}
15	0.40	0.45	1.0×10^{-3}
16	0.45	0.50	1.1×10^{-3}
17	0.50	0.55	1.2×10^{-3}
18	0.55	0.60	1.3×10^{-3}
19	0.60	0.65	1.4×10^{-3}
20	0.65	0.70	1.5×10^{-3}
21	0.70	0.80	1.6×10^{-3}
22	0.80	0.90	1.7×10^{-3}

TABLE R-3
 ACTIVITIES VERSUS TIME FOR IMPORTANT PHOTON-EMITTING
 ISOTOPES IN WEAPONS-GRADE PLUTONIUM
 (Activities in Curies in 1 Gram for Weapons-Grade Plutonium)

Isotope	0 years	1 year	15 years	70 years	200 years
²³⁷ U	0.0	7.24×10^{-6}	3.73×10^{-6}	2.74×10^{-7}	5.71×10^{-10}
²³⁸ Pu	5.06×10^{-3}	5.02×10^{-3}	4.50×10^{-3}	2.94×10^{-3}	1.07×10^{-3}
²³⁹ Pu	5.76×10^{-2}	5.76×10^{-2}	5.76×10^{-2}	5.75×10^{-2}	5.72×10^{-2}
²⁴⁰ Pu	1.27×10^{-2}	1.27×10^{-2}	1.27×10^{-2}	1.26×10^{-2}	1.24×10^{-2}
²⁴¹ Pu	3.16×10^{-1}	3.01×10^{-1}	1.55×10^{-1}	1.14×10^{-2}	2.38×10^{-5}
²⁴² Pu	1.17×10^{-6}	1.17×10^{-6}	1.17×10^{-6}	1.17×10^{-6}	1.17×10^{-6}
²⁴¹ Am	6.86×10^{-4}	1.18×10^{-3}	6.02×10^{-3}	1.01×10^{-2}	8.50×10^{-3}

* from ORIGEN calculation

TABLE B-4

DOSE RATES (MREM/HR) FOR 1 GRAM WEAPONS-GRADE PLUTONIUM IN 55-GAL LIGHT DRUM. RESULTS ARE SHOWN AT THREE RADIAL DISTANCES FROM DRUM SURFACE AND AT FIVE TIMES

		5cm	30 cm	100 cm
0 Years	²³⁷ U	0.	0.	0.
	²³⁸ Pu	2.82×10^{-4}	1.18×10^{-4}	2.80×10^{-5}
	²³⁹ Pu	1.49×10^{-2}	5.77×10^{-3}	1.30×10^{-3}
	²⁴⁰ Pu	6.29×10^{-4}	2.55×10^{-4}	5.80×10^{-5}
	²⁴¹ Pu	5.92×10^{-3}	2.38×10^{-3}	5.43×10^{-4}
	²⁴² Pu	6.08×10^{-8}	2.55×10^{-8}	6.05×10^{-9}
	²⁴¹ Am	1.87×10^{-2}	8.80×10^{-3}	2.14×10^{-3}
	Total	4.05×10^{-2}	1.73×10^{-2}	4.07×10^{-3}
1 Year	²³⁷ U	3.89×10^{-3}	1.54×10^{-3}	3.45×10^{-4}
	²³⁸ Pu	2.80×10^{-4}	1.17×10^{-4}	2.78×10^{-5}
	²³⁹ Pu	1.49×10^{-2}	5.77×10^{-3}	1.30×10^{-3}
	²⁴⁰ Pu	6.29×10^{-4}	2.55×10^{-4}	5.80×10^{-5}
	²⁴¹ Pu	5.65×10^{-3}	2.27×10^{-3}	5.18×10^{-4}
	²⁴² Pu	6.08×10^{-8}	2.55×10^{-8}	6.05×10^{-9}
	²⁴¹ Am	3.22×10^{-2}	1.51×10^{-2}	3.67×10^{-3}
	Total	5.75×10^{-2}	2.51×10^{-2}	5.92×10^{-3}
15 Years	²³⁷ U	2.00×10^{-3}	7.91×10^{-4}	1.77×10^{-4}
	²³⁸ Pu	2.51×10^{-4}	1.05×10^{-4}	2.49×10^{-5}
	²³⁹ Pu	1.49×10^{-2}	5.77×10^{-3}	1.30×10^{-3}
	²⁴⁰ Pu	6.28×10^{-4}	2.55×10^{-4}	5.79×10^{-5}
	²⁴¹ Pu	2.90×10^{-3}	1.17×10^{-3}	2.67×10^{-4}
	²⁴² Pu	6.08×10^{-8}	2.55×10^{-8}	6.05×10^{-9}
	²⁴¹ Am	1.65×10^{-1}	7.74×10^{-2}	1.88×10^{-2}
	Total	1.85×10^{-1}	8.55×10^{-2}	2.06×10^{-2}
70 Years	²³⁷ U	1.47×10^{-4}	5.81×10^{-5}	1.30×10^{-5}
	²³⁸ Pu	1.64×10^{-4}	6.85×10^{-5}	1.62×10^{-5}
	²³⁹ Pu	1.48×10^{-2}	5.76×10^{-3}	1.30×10^{-3}
	²⁴⁰ Pu	6.25×10^{-4}	2.54×10^{-4}	5.76×10^{-5}
	²⁴¹ Pu	2.13×10^{-4}	8.56×10^{-5}	1.96×10^{-5}
	²⁴² Pu	6.08×10^{-8}	2.55×10^{-8}	6.05×10^{-9}
	²⁴¹ Am	2.75×10^{-1}	1.29×10^{-1}	3.14×10^{-2}
	Total	2.91×10^{-1}	1.36×10^{-1}	3.28×10^{-2}
200 Years	²³⁷ U	3.06×10^{-7}	1.21×10^{-7}	2.72×10^{-8}
	²³⁸ Pu	5.95×10^{-5}	2.49×10^{-5}	5.90×10^{-6}
	²³⁹ Pu	1.48×10^{-2}	5.74×10^{-3}	1.30×10^{-3}
	²⁴⁰ Pu	6.16×10^{-4}	2.50×10^{-4}	5.68×10^{-5}
	²⁴¹ Pu	4.45×10^{-7}	1.79×10^{-7}	4.09×10^{-8}
	²⁴² Pu	6.08×10^{-8}	2.55×10^{-8}	6.05×10^{-9}
	²⁴¹ Am	2.33×10^{-1}	1.09×10^{-1}	2.65×10^{-2}
	Total	2.48×10^{-1}	1.15×10^{-1}	2.79×10^{-2}

TABLE B-5

DOSE RATES (MREM/HR) FROM STACK OF 55-GAL DRUMS EACH CONTAINING 1 GRAM WEAPONS-GRADE PLUTONIUM. RESULTS ARE SHOWN AT THREE DISTANCES FROM STACK FACE AND AT FIVE TIMES.

		5 cm	100 cm	500 cm
0 Years	²³⁷ U	0.	0.	0.
	²³⁸ Pu	4.98×10^{-4}	2.62×10^{-4}	2.48×10^{-5}
	²³⁹ Pu	2.64×10^{-2}	1.18×10^{-2}	1.12×10^{-3}
	²⁴⁰ Pu	1.13×10^{-3}	4.94×10^{-4}	4.52×10^{-5}
	²⁴¹ Pu	9.90×10^{-3}	4.70×10^{-3}	4.18×10^{-4}
	²⁴² Pu	1.00×10^{-7}	4.94×10^{-8}	5.01×10^{-9}
	²⁴¹ Am	2.32×10^{-2}	1.68×10^{-2}	1.92×10^{-3}
	Total	6.11×10^{-2}	3.40×10^{-2}	3.53×10^{-3}
1 Year	²³⁷ U	6.67×10^{-3}	2.89×10^{-3}	2.65×10^{-4}
	²³⁸ Pu	4.94×10^{-4}	2.60×10^{-4}	2.46×10^{-5}
	²³⁹ Pu	2.64×10^{-2}	1.18×10^{-2}	1.12×10^{-3}
	²⁴⁰ Pu	1.13×10^{-3}	4.94×10^{-4}	4.52×10^{-5}
	²⁴¹ Pu	9.44×10^{-3}	4.49×10^{-3}	3.99×10^{-4}
	²⁴² Pu	1.00×10^{-7}	4.94×10^{-8}	5.01×10^{-9}
	²⁴¹ Am	3.98×10^{-2}	2.89×10^{-2}	3.31×10^{-3}
	Total	8.40×10^{-2}	4.88×10^{-2}	5.16×10^{-3}
15 Years	²³⁷ U	3.43×10^{-3}	1.49×10^{-3}	1.36×10^{-4}
	²³⁸ Pu	4.43×10^{-4}	2.33×10^{-4}	2.20×10^{-5}
	²³⁹ Pu	2.64×10^{-2}	1.18×10^{-2}	1.12×10^{-3}
	²⁴⁰ Pu	1.13×10^{-3}	4.93×10^{-4}	4.51×10^{-5}
	²⁴¹ Pu	4.85×10^{-3}	2.31×10^{-3}	2.05×10^{-4}
	²⁴² Pu	1.00×10^{-7}	4.94×10^{-8}	5.01×10^{-9}
	²⁴¹ Am	2.04×10^{-1}	1.48×10^{-1}	1.69×10^{-2}
	Total	2.40×10^{-1}	1.64×10^{-1}	1.84×10^{-2}
70 Years	²³⁷ U	2.52×10^{-4}	1.09×10^{-4}	9.99×10^{-6}
	²³⁸ Pu	2.89×10^{-4}	1.52×10^{-4}	1.44×10^{-5}
	²³⁹ Pu	2.63×10^{-2}	1.18×10^{-2}	1.12×10^{-3}
	²⁴⁰ Pu	1.12×10^{-3}	4.90×10^{-4}	4.49×10^{-5}
	²⁴¹ Pu	3.57×10^{-7}	1.70×10^{-7}	1.51×10^{-9}
	²⁴² Pu	1.00×10^{-7}	4.94×10^{-8}	5.01×10^{-9}
	²⁴¹ Am	3.40×10^{-1}	2.47×10^{-1}	2.83×10^{-2}
	Total	3.69×10^{-1}	2.59×10^{-1}	2.95×10^{-2}
200 Years	²³⁷ U	5.26×10^{-7}	2.28×10^{-7}	2.09×10^{-8}
	²³⁸ Pu	1.05×10^{-4}	5.52×10^{-5}	5.22×10^{-6}
	²³⁹ Pu	2.63×10^{-2}	1.17×10^{-2}	1.11×10^{-3}
	²⁴⁰ Pu	1.11×10^{-3}	4.83×10^{-4}	4.43×10^{-5}
	²⁴¹ Pu	7.44×10^{-7}	3.54×10^{-7}	3.15×10^{-9}
	²⁴² Pu	1.00×10^{-7}	4.94×10^{-8}	5.01×10^{-9}
	²⁴¹ Am	2.87×10^{-1}	2.08×10^{-1}	2.39×10^{-2}
	Total	3.15×10^{-1}	2.21×10^{-1}	2.50×10^{-2}

Figure B-3. Dose rate versus time at 100 cm from 55-gal drum.

Figure B-4 indicates the spatial variation in the dose rate at 70 years for the single drum case. The corresponding plot for the stack is Figure B-5. Since the ^{241}Am peak occurs at 70 years, both Figures B-4 and B-5 show its dominance. At earlier times this dominance is reduced. Several other plots may be made from Tables B-4 and B-5. Note that at 1 meter (70 years) the dose rate from the stack is 7.9 times that from 1 drum (recall that the stack is equivalent to approximately 11 drums). This would be important should it be necessary to retrieve the waste after emplacement. However, for this study, dose exposures are estimated using 15-year old material.

Table B-6 contains ratios of total to uncollided dose rates for the seven isotopes and for each of three positions in both the drum and stack calculations. These "buildup factors" are useful in analytical calculations.

B.2 Semianalytic Dose Rate Calculations

The reason for performing these calculations is to compare results obtained using approximate methods with the more accurate Monte Carlo solution to the transport problem. In order to compare the methodology only, the same source intensities were used for both calculations. It was hoped that a good comparison would allow the use of the semianalytic method for calculating all the dose rates for various operations for the WIPP.

B.2.1 Source Characterization

Previous calculations have shown that for the reference composition specified for weapons-grade plutonium, the ^{241}Am photons are the major contributors to the dose rates external to the waste containers. Therefore, the production of ^{241}Am (in addition to that present initially) resulting from the beta decay of ^{241}Pu is an important consideration in evaluating the radiological effects of long-term storage. Calculations were made, using the ORIGEN code,⁵ to determine the activities of the various isotopes as a function of time. The input

Figure B-4. Dose rate versus distance from surface of one 55-gal drum. Time = 70 years (maximum dose rates).

Figure B-5. Dose rate versus distance from face of stack of 55-gal drums. Contents of drum normalized to 1 g of plutonium. Time = 70 years (maximum dose rate).

TABLE B-6

RATIOS OF TOTAL TO UNCOLLIDED DOSE RATES

Nuclide	Drum			Stack		
	5 cm	30 cm	100 cm	5 cm	100 cm	500 cm
^{237}U	1.80	1.81	1.84	2.30	2.31	2.48
^{238}Pu	1.87	1.91	1.91	2.50	2.49	2.52
^{239}Pu	1.74	1.75	1.78	2.07	2.39	2.65
^{240}Pu	1.90	1.91	1.93	3.29	2.46	2.58
^{241}Pu	1.99	1.99	2.05	2.39	2.66	2.76
^{242}Pu	1.89	1.88	1.94	2.31	2.40	2.60
^{241}Am	1.97	1.99	1.99	2.06	2.39	2.67

to the code was the weight fractions for 1 gram of the reference composition of weapons-grade plutonium. Using this information, ORIGEN then computes the individual activities for specified decay times; the reference composition is defined as the composition at 'zero time.' The code follows the decay chains of interest and prints out data for the new radionuclides formed as a result of the radioactive decay. Based on an examination of what other isotopes should be included, it was found that ^{237}U might be an important contributor to the activities. In Table B-7 the activities, in curies, for decay times in the range from 0 to 200 years are shown. The maximum activity for ^{241}Am occurs at 70 years; the buildup is impressive, a factor of 15 in activity from 0 to 70 years.

The source specifications for weapons-grade plutonium were given in terms of the weight percent of the various isotopes, and these are shown in Table B-7. The source energies and intensities were derived from the Julich library² of gamma-ray and x-ray lines for 1,313 radionuclides. For the problem at hand, the discrete lines were binned into a 90-group structure from 0 to 0.9 MeV in 0.01-MeV intervals as shown in Table B-1.

TABLE B-7

SOURCE SPECIFICATIONS FOR 1 GRAM WEAPONS-GRADE PLUTONIUM
(Activities in Curies Computed Using ORIGEN Code)

Isotope	Reference Composition		Activity Following Decay Time (year) of					
	Wt Percent	Activity	1	10	30	70	100	260
^{237}U	0.	0.	7.24×10^{-6}	4.72×10^{-6}	1.83×10^{-6}	2.74×10^{-7}	6.59×10^{-8}	5.71×10^{-10}
^{238}Pu	0.03	5.06×10^{-3}	5.02×10^{-3}	4.68×10^{-3}	4.01×10^{-3}	2.94×10^{-3}	2.32×10^{-3}	1.07×10^{-3}
^{239}Pu	93.88	5.76×10^{-2}	5.76×10^{-2}	5.76×10^{-2}	5.75×10^{-2}	5.75×10^{-2}	5.74×10^{-2}	5.73×10^{-2}
^{240}Pu	5.75	1.27×10^{-2}	1.27×10^{-2}	1.27×10^{-2}	1.26×10^{-2}	1.26×10^{-2}	1.26×10^{-2}	1.24×10^{-2}
^{241}Pu	0.31	3.16×10^{-1}	3.01×10^{-1}	1.97×10^{-1}	7.61×10^{-2}	1.14×10^{-2}	2.74×10^{-3}	2.38×10^{-5}
^{242}Pu	0.03	1.17×10^{-6}	1.17×10^{-6}	1.17×10^{-6}	1.17×10^{-6}	1.17×10^{-6}	1.17×10^{-6}	1.17×10^{-6}
^{241}Am	0.02	6.86×10^{-4}	1.18×10^{-3}	4.67×10^{-3}	8.51×10^{-3}	1.01×10^{-2}	9.88×10^{-3}	8.50×10^{-3}

Actually, the photon energies of interest are below 0.4 MeV, but the source input for the Monte Carlo runs included energies up to 0.9 MeV. Although this capability was not used, the ORIGEN code computes the photons/second at mean energies from 0.03 to 5.25 MeV. For the reference composition, the ORIGEN value for a mean energy of 0.06 MeV is 9.2×10^6 as compared to our source of 9.5×10^6 photons/second in the 0.05 to 0.06 MeV interval. In the range from 0.01 to 0.4 MeV, our source strengths are about a factor of 2 higher than the ORIGEN calculations. Finally, note that the ORIGEN source strengths for mean energies above 0.63 MeV are no more than 44 photons/second, an insignificant number compared to those for the softer photons.

As mentioned before, the source intensities for the Monte Carlo problems were given in 0.01-MeV intervals for energies between 0 and 0.9 MeV. In lieu of performing the approximate calculations using the latter source description, the following procedure for reducing the number of groups was adopted. First, the energy bins (in the 90-group set) with photons/second below 10^4 /second were neglected; the groups that were retained are listed in Table B-8. Above 0.42 MeV, and with only two exceptions, the group intensities were below 500 photons/second. A further thinning out of the energy bins can be made by examination of the variation of the linear attenuation coefficient (μ) versus energy. These figures, together with the number of mean free paths in the side wall of the drum and a thickness of 0.24 g/cm^3 are displayed in Table B-9. Combining the information in Tables B-8 and B-9, we conclude that photons below 0.05 MeV can be ignored in the calculations.

Because ^{241}Am is an important contributor to the dose rate, the group between 0.05 and 0.06 MeV is retained as a unique group. This was also done because the Monte Carlo results yield information on the dose-rate contributions by group and isotope. The 0.05-0.06 group will be used as the main basis of comparison for the two methods. The energy region between 0.06 and 0.42 MeV was collapsed into two groups, from 0.06 to 0.15, and 0.20 to 0.42 MeV. Weighting the intensities with the average energy in a group, one arrives at 0.104 and 0.367 MeV for the average energies of the groups; for convenience these energies will be

TABLE B-8
 PHOTONS/SECOND FOR 1 GRAM WEAPONS-GRADE
 PLUTONIUM-REFERENCE COMPOSITION
 (Computed for Selected Energy Intervals from Jülich Data)

<u>Energy (MeV)</u>	<u>Photons/second</u>
0.01-0.02	1.49×10^7
0.02-0.03	2.69×10^7
0.03-0.04	2.39×10^5
0.04-0.05	1.48×10^5
0.05-0.06	9.47×10^6
0.06-0.07	1.64×10^4
0.07-0.08	1.85×10^4
0.09-0.10	7.42×10^5
0.10-0.11	7.39×10^4
0.11-0.12	2.96×10^5
0.12-0.13	1.25×10^5
0.14-0.15	3.08×10^4
0.20-0.21	1.09×10^4
0.33-0.34	1.15×10^4
0.34-0.35	1.19×10^4
0.37-0.38	3.23×10^4
0.38-0.39	1.17×10^4
0.39-0.40	1.17×10^4
0.41-0.42	3.22×10^4

TABLE B-9

LINEAR ATTENUATION COEFFICIENTS (cm^{-1}) FOR 0.24 g/cm^3
CARBON (μ_{C}) AND 7.86 g/cm^3 IRON (μ_{Fe})

(Mean free paths for $t_{\text{C}} = 28.5 \text{ cm}$ and $t_{\text{Fe}} = 0.109 \text{ cm}$)

<u>Photon Energy (MeV)</u>	<u>μ_{C}</u>	<u>μ_{Fe}</u>	<u>$\mu_{\text{C}} t_{\text{C}}$</u>	<u>$\mu_{\text{Fe}} t_{\text{Fe}}$</u>
0.01	0.508	1352.	14.5	147.
0.015	0.169	438.	4.81	47.6
0.02	0.0908	197.	2.58	21.4
0.03	0.0538	61.9	1.53	6.73
0.04	0.0452	27.2	1.29	2.96
0.05	0.0419	14.5	1.19	1.58
0.06	0.0398	8.88	1.13	0.965
0.08	0.0370	4.32	1.05	0.470
0.10	0.0351	2.69	0.999	0.292
0.15	0.0314	1.45	0.894	0.158
0.20	0.0288	1.09	0.820	0.118
0.30	0.0250	0.841	0.712	0.0914
0.40	0.0223	0.724	0.635	0.0787

taken as 0.1 and 0.4 MeV. Summarizing, the source description for the approximate calculations (zero decay time) are the following:

$$\begin{aligned}\bar{E} &= 0.06 & 9.47 \times 10^6 \\ &= 0.10 & 1.31 \times 10^6 \\ &= 0.40 \text{ MeV} & 1.11 \times 10^5 \text{ photons/second.}\end{aligned}$$

B.2.2 Dose Rates Exterior to a Single Drum

The geometry assumed for the calculation of dose rates exterior to a drum is shown in Figure B-6. Only detector locations along a line perpendicular to the cylinder axis and at midheight are considered. As given in the Engineering Compendium on Radiation Shielding,⁶ the uncollided flux at P is given by

$$\phi_u = \frac{S_v R^2}{2(a+z)} \times F(\theta, b_2) = \frac{Q}{2\pi h(a+z)} \times F(\theta, b_2)$$

where

- S_v = volumetric source (photons/cm³-s)
- Q = source strength (photons/second)
- h = height of drum = 88.6 cm
- a = distance from drum surface to detector (cm)
- z = self-absorption distance (cm)
- μ_c = linear attenuation coefficient for 0.24 g/cm³ carbon
- μ_{Fe} = linear attenuation coefficient for 7.86 g/cm³ Fe
- t_{Fe} = drum wall thickness = 0.109 cm
- b_2 = $\mu_c z + \mu_{Fe} t_{Fe}$
- R = radius of drum = 28.6 cm.

The Monte Carlo problems were run for detector locations (a) equal to 5, 30, and 100 cm. The above formula turns out to be not applicable for a/R less than 1; therefore, only the 30 and 100 cm detector positions were computed. The self-absorption distance z is a function of a/R, $\mu_c(a+R)$, and $\mu_{Fe}t_{Fe}$; it is obtained from curves given in Reference 6. Note that the problem has been treated as if the steel wall were a slab

Figure B-6. Geometry for cylindrical volume source with slab shield at side and "self-absorption" distance (z).

shield. The flux-to-dose-rate conversion factors, according to an American National Standard document,⁴ were 2.7×10^{-4} , 2.8×10^{-4} and 9.9×10^{-4} (mrem/hr)/(photon/cm²-s) at energies of 0.06, 0.1, and 0.4 MeV, respectively. The uncollided dose rates at 30 and 100 cm were computed using approximate methods and for zero decay time and are 1.4×10^{-2} and 3.4×10^{-3} mrem/hr, respectively (Table B-10). The contribution from ²⁴¹Am to these dose rates is 9.2×10^{-3} and 2.3×10^{-3} . Using the semianalytic method, it is not possible to calculate the dose rate at 5 cm from the surface of the drum. However, the upper limit for the drum surface dose rate was estimated to be 0.078 mrem/hr of which 0.054 mrem/hr is due to ²⁴¹Am. The lower limit, unfortunately, is zero, but a good estimate for the surface dose rate would be the average, 0.039 mrem/hr.

At this point in the calculations, one is faced with the problem of assigning the buildup factors needed to convert the uncollided quantities to actual dose rates. This is not so difficult for gamma-rays above 0.5 MeV, because tabulations exist that give buildup factors for various materials, and as a function of energy and number of mean free paths. In our case, where the important energy range is below 0.1 MeV, obtaining a buildup factor that is at all realistic becomes a major problem. Without recourse to Monte Carlo calculations to compute buildup factors, the best that one could do for the problem at hand would be to state that the actual dose rate is a factor of a few higher than those shown in Table B-10. Obviously, the calculation to obtain the buildup factor also gives the total dose rate. In any event, the buildup factors are available from the Monte Carlo runs, and these are used to correct the uncollided values. The buildup factor is obtained by dividing the total dose rate by the direct (uncollided) dose rate. The approximate buildup factor is 2 in this case. Results of applying this factor will be given later. A comparison of the approximate and Monte Carlo calculations is made in Section B.3.

TABLE B-10

UNCOLLIDED FLUXES AND DOSE RATES EXTERNAL
TO A SINGLE DRUM CONTAINING 1 GRAM OF WEAPONS-GRADE PLUTONIUM

(Detectors at 30 and 100 cm from Surface of Drum
Semianalytic Method - Zero Decay Time)

$\bar{E}$ (MeV)	Q (photons/second)	θ (°)	b_2	$F(\theta, b_2)$	ϕ_u (cm ⁻² s ⁻¹)	mrem/hr (uncollided)
0.06	9.47×10^6					
a 30 cm		41	1.7	0.10	34.1	9.2×10^{-3}
a 100 cm		20	1.8	0.06	8.5	2.3×10^{-3}
0.1	1.31×10^6					
a 30 cm		41	1.0	0.24	11.3	3.2×10^{-3}
a 100 cm		20	1.0	0.14	2.8	7.7×10^{-4}
0.4	1.11×10^5					
a 30 cm		41	0.5	0.41	1.7	1.7×10^{-3}
a 100 cm		20	0.5	0.20	0.3	2.9×10^{-4}
Total						
a 30 cm						1.4×10^{-2}
a 100 cm						3.4×10^{-3}

B.2.3 Dose Rates External to a Stack

Next, the dose rates at detector locations external to a stack of 55-gal drums are considered. This geometry was modeled in the Monte Carlo calculations as a cylinder of 57.2 cm height and radius equal to 265.7 cm. The geometry appropriate to this problem is shown in Figure B-7 with the distance from the detector point to the top surface of the cylinder defined as "a." The formulae that apply for the approximate calculations are given in Reference 6 and will not be reproduced here. The solutions give an upper and lower limit for the dose rates. In the case of a cylinder height greater than three mean free paths (carbon in our case), the formulae reduce to a simpler form. The results obtained are listed in Table B-11. Note that these values are uncollided quantities and for the reference composition, namely, zero decay time.

B.3 Comparison of Calculations Using Monte Carlo and Semianalytic Methods

The dose rates computed for the single drum and stack geometries are summarized in Table B-12. For the stack geometry, the dose rates shown represent an average of the upper and lower limits from the approximate calculations. The agreement is within a factor of 2 for the single drum and no greater than a factor of 3 for the stack array. As indicated earlier, this rather good agreement could only be obtained because the buildup factors were known from the Monte Carlo calculations. But given the correct buildup information, the semianalytic methods can yield results that should be good to about a factor of 2.

It can thus be assumed that the semianalytic methods can be used for evaluating operator dose exposures for various operators and geometries in WIPP. The results obtained can be assumed to overestimate the actual dose rates by a factor of 2 to 3. Given the uncertainty in the drum contents, the error in the calculational results is not bad and adds a degree of conservatism.

Figure B-7. Geometry for cylindrical volume source with slab shield at end; "truncated cone" approximation.

TABLE B-11

APPROXIMATE CALCULATIONS FOR A STACK ARRAY. DOSE RATES BASED ON UNCOLLIDED FLUX VALUES
(Radius of Cylinder is 265.7 cm and Height is 57.2 cm. Zero Decay Time)

	Detector Location		
	5 cm	100 cm	500 cm
mrem/hr total			
Upper limit	0.032	0.022	0.0036
Lower limit	0.025	0.017	0.0036
mrem/hr - ^{241}Am			
Upper limit	0.021	0.015	0.0021
Lower limit	0.011	0.010	0.0021

TABLE B-12
COMPARISON OF CALCULATIONS USING MONTE CARLO
AND SEMIANALYTIC METHODS

(Zero Decay Time)

	<u>Monte Carlo</u>	<u>Semi-analytic</u>	<u>Buildup factor</u>	<u>Semianalytic w/buildup</u>	<u>Ratio: Semianalytic Monte Carlo</u>
(A) Single Drum					
a 30 cm					
mrem/hr - total	1.73×10^{-2}	1.4×10^{-2}	2	2.8×10^{-2}	1.6
mrem/hr - ^{241}Am	8.80×10^{-3}	9.2×10^{-3}	2	1.8×10^{-2}	2.0
a 100 cm					
mrem/hr - total	4.07×10^{-3}	3.4×10^{-3}	2	6.8×10^{-3}	1.6
mrem/hr - ^{241}Am	2.14×10^{-3}	2.3×10^{-3}	2	4.6×10^{-3}	2.1
(B) Stack Geometry					
a 5 cm					
mrem/hr - total	6.11×10^{-2}	2.9×10^{-2}	2	5.8×10^{-2}	0.95
mrem/hr - ^{241}Am	2.32×10^{-2}	1.6×10^{-2}	2	3.2×10^{-2}	1.4
a 100 cm					
mrem/hr - total	3.40×10^{-2}	2.0×10^{-2}	2.4	4.8×10^{-2}	1.4
mrem/hr - ^{241}Am	1.68×10^{-2}	1.3×10^{-2}	2.4	3.1×10^{-2}	2.9
a 500 cm					
mrem/hr - total	3.53×10^{-3}	3.6×10^{-3}	2.5	9.0×10^{-3}	2.6
mrem/hr - ^{241}Am	1.92×10^{-3}	2.1×10^{-3}	2.5	5.3×10^{-3}	2.8

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APPENDIX C
RADIATION DOSE-RATE CALCULATIONS

APPENDIX C
RADIATION DOSE-RATE CALCULATIONS

C.1 Radioactive Sources in WIPP

Dose-rate calculations were performed by using the semianalytic methods discussed in Appendix B of this report and used for a previous study of WIPP operator dose exposures.¹ All of the calculations were performed for a drum containing 1 gram of weapons-grade plutonium. Thus, all of the results shown are on a per gram basis and can be increased or decreased linearly depending on the contents of a drum. The quantities and types of radionuclides in the waste vary significantly, however; so that a better way to apply the results would be to adjust the source relative to the surface dose rate, as will be shown later.

It should also be noted that all results are based on weapons-grade plutonium aged 15 years from initial separation. This is important, because at 70 years after separation, the ^{241}Am contribution can increase over the 15-year old material by a factor of 1.7. Because ^{241}Am is the main contributor, this means that should it become necessary to remove the waste at later times, the dose rates could be a factor of 2 to 15 higher than when it was emplaced. Also, if the dose rate at emplacement is substantially due to fission products or actinides not found for the most part in weapons-grade plutonium, the gamma hazard from the fission products may decrease over the years only to be replaced by the ^{241}Am gamma hazard.

The waste will be introduced to the WIPP in drums, fiber-glass-reinforced polyester (FRP) boxes, and modular steel boxes. Only the waste drums are addressed in this study, because they represent the worst case as far as potential radiation dose. The drums would be loaded 24 drums per pallet. Only two FRP boxes would be loaded per pallet which would represent a smaller and more dispersed source.² The modular steel boxes could contain up to six drums or their contents, would be loaded four boxes per pallet, and would thus present a source

similar to a pallet of drums. The modular steel boxes have slightly thicker sides, however; thus the single drums are used as the worst case.

The various operations and associated gamma-ray source geometries have been discussed in Appendix A. For the five basic cases considered, there are seven unique source geometries to be considered. A description of each source is contained in Table C-1. The dose rate as a function of distance for each of the seven sources is shown in Figure C-1.

TABLE C-1
RADIATION SOURCE GEOMETRIES FOR WIPP

<u>Source Number</u>	<u>Radiation Source</u>	<u>Source Description</u>
1	Single drum	A single 55-gal drum of waste
2	Six-pack	Six drums in a 2 x 3 array
3	Pallet	Four six-pack with drums in a 4 x 6 array
4	Shipping container	Operator sees a stack face in a 2 x 3 drum array
5	Pallets at CH handling area	Pallets arranged in a long row in the CH handling area
6	Surge storage	Pallets stacked 3 drums high x 24 drums long in the surge storage area
7	Underground stack	Stack of drums in the underground storage room. Stack face is 3 x 15 drum array

C.2 Operator Radiation Exposures

The dose-rate mappings from Section C-1 were folded with the time and motion sequences of Appendix A. The operators considered were the following: 1) forklift operator (underground storage area), 2) transporter operator (underground), 3) forklift operator (shipping container unloading, one drum per trip), 4) forklift operator (pallet shuttle),

Figure C-1. Dose rate versus distance for seven sources.

and 5) forklift operator (shipping container unloading, one six-pack per trip). The results of these calculations are shown in Table C-2. It should be noted that these results are based on a waste drum containing 1 gram of 15-yr-old weapons-grade plutonium with a surface dose rate of 0.164 mrem/hr. These results would increase by about a factor of 2 for 70-year old material.

Because of the diversity of waste materials, including weapons-grade plutonium, weapons-grade plutonium contaminated with excess ^{241}Am and/or fission products, heat source plutonium, etc., it is perhaps more appropriate to normalize the results to the surface dose-rate rather than to the quantity of source material. The uncertainty even in the surface dose-rate of the drums is quite high; however, actual measurements are available, whereas inventories of drum contents are not available, for the most part. Although the surface dose rates can go as high as 200 mrem/hr, the average for drums stored at the Idaho Nuclear Engineering Laboratory is about 3 mrem/hr. This would increase the results of Table C-2 by a factor of six because the surface dose rate calculated here is 0.5 mrem/hr (average). The average dose exposures are presented in Table C-3.

There are possibly other operations personnel who have not been addressed in this study. This includes an operator who assembles six-packs, health physics personnel, and the backfill crew. A lack of specific data defining their tasks precludes a calculation to estimate their potential dose exposures at this time; however, during Title II, estimates of their potential dose exposure should be made.

TABLE C-2

OPERATOR DOSE EXPOSURES

Case	Source	Description	Dose*		
			(mrem per yr)		
1		Underground Storage Room Forklift Operator	<u>1.1</u>	<u>1.2</u>	<u>1.3</u>
	a	- stack	684	114	142
	b	- drums carried	50	32	27
	c	- pallet on floor	46	6	7
		TOTAL	780	152	176

2	a	Transporter Operator - pallet dose	<u>2.1</u>	<u>2.2</u>	
		- pallet	13.5	18	

3		Shipping Container Unloading Forklift Operator	<u>3.1</u>	<u>3.2</u>	<u>3.3</u>
	a	- stack dose (shipping container)	91	15	12.6
	b	- drum(s) carried	16	10	21.5
	c	- pallets at CH handling (or airlock)	123	20	26.6
	d	- surge area	51	8	10.0
		TOTAL	281	53	71.0

4		Pallet Shuttle Forklift Operator			
	a	- pallets at CH handling		7.3	
	b	- pallet carried		6.9	
	c	- surge storage area		2.5	
		TOTAL		16.7	

* Assumes 1 gram plutonium per drum.

TABLE C-3
OPERATOR DOSE EXPOSURES

<u>Case</u>	<u>Operator</u>	<u>Dose* (mrem)</u>		
		<u>1.1</u>	<u>1.2</u>	<u>1.3</u>
1.1	Forklift Operator - Underground Storage Room	4104	684	852
1.2		300	192	162
1.3		276	36	42
1 Total		4680	912	1056
<hr style="border-top: 1px dashed black;"/>				
2 Total	Transporter Operator - Underground	2.1 81	2.2 108	
<hr style="border-top: 1px dashed black;"/>				
3.1	Forklift Operator - Shipping Container Unloading, One Drum Per Trip	3.1 546	3.2 90	3.3 76
3.2		96	60	129
3.3		738	120	160
3d		306	48	60
3 Total		1686	318	426
<hr style="border-top: 1px dashed black;"/>				
4a	Forklift Operator - Pallet Shuttle		44	
4b			41	
4c			15	
4 Total			100	
<hr style="border-top: 1px dashed black;"/>				

* Assumes surface dose rate of 3 mrem/hr for drum.

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