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Yucca Mountain Site Characterization Project

Waste Package Emplacement Borehole Option Study

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WASTE PACKAGE EMPLACEMENT BOREHOLE OPTION STUDY

Prepared by
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San Francisco, California

Under Sandia Contract 57-0878

for
Nuclear Waste Repository Technology
Sandia National Laboratories
Albuquerque, New Mexico

Abstract

This study evaluates the cost and thermal effects of various waste package emplacement configurations that differ in emplacement orientation, number of containers per borehole, and standoff distance at the potential Yucca Mountain nuclear waste repository. In this study, eight additional alternatives to the vertical and horizontal orientation options presented in the Site Characterization Plan Conceptual Design Report are considered. Typical panel layout configurations based on thermal analysis of the waste and cost estimates for design and construction, operations, and closure and decommissioning were made for each emplacement option. For the thermal analysis average waste 10 years out of reactor and the SIM code were used to determine whether the various configuration temperatures would exceed the design criteria for temperature. This study does not make a recommendation for emplacement configuration, but does provide information for comparison of alternatives.

QUALITY ASSURANCE

This report was done in accordance with Sandia National Laboratories (SNL) Design Investigation Memo (DIM) 102 and under WBS 1.2.4.3.4. The DIMs are controlled by the SNL Department Operating Procedure titled "Design Investigation Control," DOP 3-4, which details the methods for (1) planning, (2) documenting, (3) initiating, (4) accepting, and (5) reviewing a design investigation task.

Parsons Brinckerhoff Quade & Douglas, Inc. has had many years experience in the engineering and architectural field and has worked under contract to SNL on the mined geological disposal system and is qualified to work in the technical areas of this report.

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TABLES

FIGURES

1.0 INTRODUCTION

This report presents an analysis of ten emplacement options for the potential nuclear waste repository in tuff. Typical panel layout configurations based on waste thermal analysis were prepared, and cost estimates for engineering and construction, operations, and closure and decommissioning were made for each emplacement option. The analysis and data herein were developed to support other studies and analysis; this report is not intended to present any conclusion as to a preferred or optimum option. Some general trends in thermal analysis results and cost estimates are provided.

The report is organized into four sections following this introduction. Section 2 presents the bases for the study, including the regulatory requirements, assumptions, and qualifications used. Section 3 describes the different emplacement options and presents estimates of their costs. Section 4 briefly discusses the results of the study. Section 5 is a list of references.

2.0 BASES FOR EMPLACEMENT ORIENTATION STUDY

2.1 Bases of the Design

2.1.1 Waste Characteristics

Waste characteristics for average waste that has been out of a reactor for 10 yr have been developed for the thermal analyses in this study. The values for heat load and areal heat load (AHL) are the following.

Heat Load (Watts/container)

- Spent Fuel (SF)
  - maximum is 3156 W (calculated for a consolidated container made up of six PWR assemblies)
  - average is 2731 W (calculated for a mix of consolidated containers that include PWR or BWR, and the total of these containers is 60% PWR and 40% BWR by weight [SNL, 1987, Appendix P])
  - spent fuel waste has an average burnup value of 33,000 MWD/MTU for PWR fuel and 27,500 MWD/MTU for BWR fuel (SNL, 1987, Appendix P).
- Defense High Level Waste (DHLW)
  - maximum is 470 W (from SNL, 1987)
  - average is 200 W (from SNL, 1987, Appendix P).

Areal Heat Load (kW/acre)

- The 57 kW/acre given for average waste characteristics (Johnstone et al., 1984) were adjusted according to procedures set by Mansure in Appendix G of the SCP-CDR (SNL, 1987) resulting in 54.6 kW/acre. Areal heat load includes energy from both spent fuel and DHLW.

2.1.2 Physical and Thermal Constraints

A 7.5-foot centerline-to-centerline borehole spacing (nominal 3 times borehole diameter) was used to maintain structural integrity of the 29-inch-diameter vertical boreholes. Similarly, for 37-inch-diameter horizontal boreholes a minimum spacing between holes of 9.5 feet was used.

Thermal analysis is based on the AHL, which was determined by Johnstone et al. (1984) to be 57 kW/acre for the potential repository horizon unit. However, because the decay characteristics used in Johnstone's unit evaluation were later adjusted for data contained in "Generic Requirements for a Mined Geologic Disposal System" (DOE, 1984), the initial AHL was corrected to 54.6 kW/acre for a mix of 60% PWR and 40% BWR spent fuel wastes (SNL, 1987, Appendix G).

The design criteria stipulate that temperatures at the borehole walls are not to exceed 235°C (455°F) and 200°C (392°F) 1 m from the borehole walls during the lifetime of the potential repository. Thermal analysis of these near-field effects was performed using the maximum container heat output (CHO) for all waste containers.

To determine temperatures in emplacement and panel access drifts, the average CHO values were used. The temperatures in the emplacement drifts are constrained in only one of the emplacement options, Case 14-H (SCP-CDR Alternate Case). In this case, the drift temperature must not exceed 50°C (122°F) for 50 yr after waste is emplaced. The goal for the panel access drift in all cases is that the temperature not exceed 50°C for 50 yr.

2.1.3 Borehole Pattern

One attribute of the design that varies between cases is the borehole pattern. The two patterns evaluated in this analysis are the alternating pattern and the sandwich pattern. In the alternating pattern, spent fuel waste is alternated with DHLW waste, and there are equal numbers of containers in each hole. The sandwich pattern consists of three boreholes--two with spent fuel and one with DHLW. More DHLW containers are emplaced in the sandwiched borehole than spent fuel in either of the two spent fuel boreholes. The overall mix of waste in both of these patterns allows emplacement of approximately equal numbers of each type of container in an emplacement drift.

The two possible patterns for each case resulted from the design criteria that specified only the maximum depth of borehole and number of spent fuel containers. Because the DHLW containers are only 11 ft long (length with emplacement skid in a horizontal borehole), compared to 16 ft for spent fuel containers, several options were available for the design of the DHLW borehole configuration: the same number of containers could be put in the same length borehole, the boreholes could have been made shorter, or more DHLW containers could be emplaced in the borehole and the number of DHLW boreholes reduced. Using the same length boreholes for DHLW and SF would be inefficient because of the unused space in the DHLW borehole. The other two alternatives resulted in the alternating and sandwich patterns.

2.2 Assumptions and Qualifications

The assumptions and qualifications used to develop the layout options for emplacement orientation and the cost estimates are presented below.

- The waste transporter/cask mechanism can be developed to push the waste container to a standoff of 20 ft without a significant change in transporter purchase or operating cost.

- Achievement of a waste container standoff greater than 20 feet can be accomplished by (1) use of dummy containers or empty dollies which are emplaced in the borehole in the same manner as that used for a waste container, (2) use of very low thermal output DHLW containers in the last few containers emplaced (and then using a 20-foot standoff), or (3) the use of a pusher mechanism (which may be combined with a retrieval transporter). This study assumed that the latter method of a separate transporter/pusher unit is used. While the details of the design of a unit capable of pushing canisters into the borehole are not available, for the purposes of this study it was a conservative assumption that this unit is similar to the waste transporter and therefore utilized the purchase and operating costs of the waste transporter.

- Developing the short horizontal boreholes includes drilling a pilot hole, reaming to full diameter, and then installing the liner. The technology, methodology, and basis for productivities used were developed and reported by the Robbins Company.[1]

- Rock termal property values used in this report vary slightly from current RIB values. A comparison of values is presented in the appendix.

2.3 Emplacement Borehole Options

This study considers eight additional alternatives to the vertical and horizontal orientation options presented in the SCP-CDR (MacDougall et al., 1987). The cases presented in this report are summarized in Table 2-1.

TABLE 2-1

EMPLACEMENT BOREHOLE OPTIONS

Emplacement Orientation	Number of Waste Containers	Borehole Pattern	Spent Fuel Standoff	Case Number
Vertical	1	Alternating	10 ft	1-V
			20 ft	1-VA
Horizontal	1	Sandwich	20 ft	1-H
			10 ft	1-HA
		Alternating	10 ft	1-HB
			20 ft	1-HC
	2	Alternating	20 ft	2-H
	3	Sandwich	20 ft	3-H
	14	Sandwich	94 ft	14-H
			20 ft	14-HA

1. The Robbins Company, "Boring and Lining Horizontal Emplacement [illegible]," SAND88-7123 (unpublished, in process), 1989.

3.0 EMPLACEMENT ORIENTATION OPTIONS

3.1 Methodology for Layout Design

The thermal analysis and layout preparation for each alternative are designed to provide a configuration of the drifts and emplacement boreholes that meets the physical and thermal constraints while providing a functional operation. In addition, construction and operating costs are addressed for each alternative. Construction costs were reduced by spacing boreholes as close as possible given the thermal and physical constraints. The close borehole spacing allows for a greater number of waste containers to be emplaced in each drift, which in turn reduces drift spacing and the footage of the emplacement drifts. In addition to the direct cost of emplacement drift construction, several other operating costs are influenced by changes in emplacement drift layout, including ventilation and drift maintenance. Each of these costs will also be reduced by lowering the drift footage.

The layout and thermal analysis is performed as an iterative procedure where the layout dimensions (borehole and drift spacings) are assumed and/or calculated, and thermal calculations are run to determine if the layout dimensions result in temperatures around the waste that satisfy the constraints.

The layout dimensions are determined for the smallest workable design unit, also called the modular design unit (MDU) (Figure 3-1). The equation for calculation of areal heat load (AHL) for an MDU with commingling waste is

$$AHL = \frac{\left(\text{Ave CHO}_{SF} \bullet N_{SF}\right) + \left(\text{Ave CHO}_{DHLW} \bullet N_{DHLW}\right)}{y \bullet w} \bullet \frac{\left(43{,}560\ ft^2\right)}{acre}$$

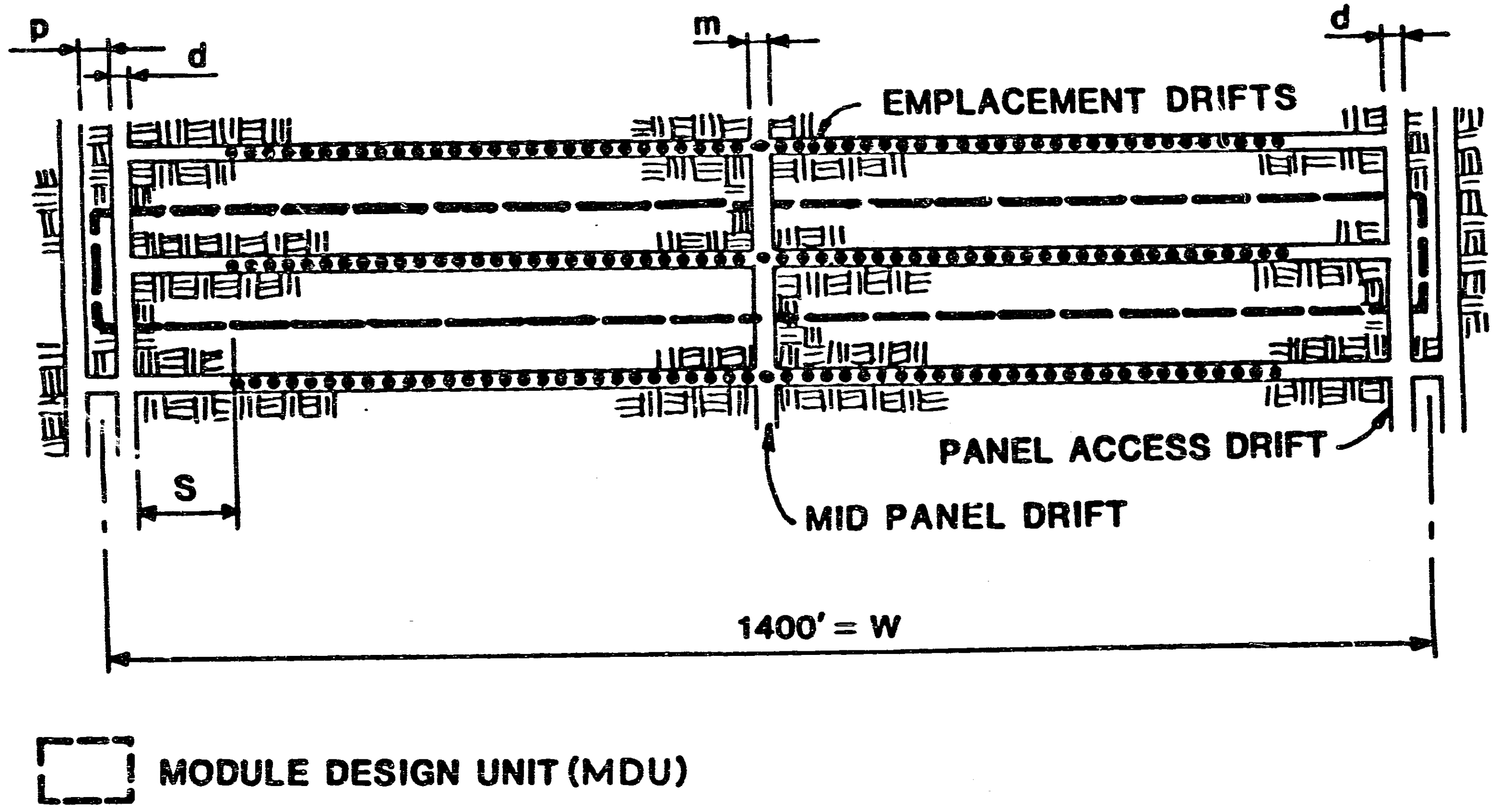

Figure 3-1. Module Design Unit

where

AHL = areal heat load

Ave CHO_{SF} = average container heat output for spent fuel

N_{SF} = number of spent fuel containers in the MDU

Ave CHO_{DHLW} = average CHO for DHLW

N_{DHLW} = number of DHLW containers in the MDU

y = distance between emplacement drifts

W = panel width = 1,400 ft.

For each iteration, a borehole spacing value is selected based upon previous calculations. The equation can then be reduced to a calculation of the distance between emplacement drifts. The average CHOs, AHL, and W are constant for this analysis, and the number of spent fuel and DHLW containers is determined from the borehole spacing and number of containers per hole. The standoff between the panel access drift and the first spent fuel or DHLW container is also calculated from the MDU layout dimensions.

Thermal analysis is run using the SIM code, first to check the temperatures near the boreholes and then to check the temperatures of the emplacement and panel access drifts. SIM is a conductive heat transfer code for three-dimensional thermal analysis of an infinite medium subject to exponentially decaying thermal loading. The code is based on a closed form solution that models the patterns of finite line sources in a rock mass. Thermal decay curves for each waste type used in these calculations are taken from work completed at Oak Ridge National Laboratory as reported in the SDR.

For the temperature calculations near the boreholes, the higher temperature scenario occurs when all of the emplaced waste is assumed at the maximum CHO for the hottest waste type. This provides a conservative design which can accommodate the fairly wide range of CHOs expected from the waste to be emplaced. If any of the thermal constraints are not met, the borehole spacing, number of boreholes per drift, and drift spacing were adjusted, and the thermal analyses are run again for the new values. An acceptable design satisfies thermal constraints, minimizes cost, and provides for efficient operation.

Table 3-1 summarizes the results of the layout and thermal calculations performed for the emplacement options.

3.2 Optional Layouts for Orientation Panels

3.2.1 Vertical Case 1-V (Reference Case)

Case 1-V considers one spent fuel container in a 25-ft vertical borehole alternating with one DHLW container in a 20-ft borehole. These lengths include a standoff of about 10 ft from the waste container to the drift floor (Figure 3-2).

Based upon the minimum borehole spacing, the spacing between spent fuel and DHLW containers is 7.5 ft (15 ft between spent fuel boreholes) and the emplacement drift spacing is 126 ft. Because the borehole spacing is limited by the minimum spacing constraint, the temperatures around the boreholes do not reach allowable maximums.

3.2.2 Horizontal Case 14-H (Alternate Case)

Case 14-H considers 14 spent fuel containers in a 363-ft borehole or 18 DHLW containers in a 297-ft borehole. These borehole lengths include a standoff of 134 ft for the spent fuel boreholes and 94 ft for the DHLW boreholes, measured from the last waste container to the drift wall. A sequence of three boreholes (spent fuel, DHLW, spent fuel) is repeated along both sides of the emplacement drift (Figure 3-3).

Based upon thermal constraints, the spacing between spent fuel containers is 72 ft when there is a DHLW container in between and 68 ft when there is no DHLW container in between. The emplacement drift spacing is 748 ft.

TABLE 3-1

SUMMARY OF LAYOUT AND THERMAL INFORMATION

Layout Information	Case 1-V	Case 14-H	Case 1-H	Case 1-HA	Case 1-HB	Case 1-HC	Case 2-H	Case 3-H	Case 14-HA	Case 1-VA
Spent fuel containers/hole	1	14	1	1	1	1	2	3	14	1
Length of spent fuel hole (ft)	25	363	42	32	32	42	58	75	249	35
Standoff of spent fuel hole (ft)	10	134	20	10	10	20	20	20	20	20
Spent fuel (no./hole x hole/row)	1x75=75	14x16=224	1x78=78	1x76=76	1x61=61	1x61=61	2x48=96	3x36=108	14x16=224	1x75=75
DHLW container/hole	1	18	2	2	1	1	2	5	18	1
Length DHLW hole (ft)	20	297	42	37	27	37	42	75	223	30
Standoff-DHLW hole (ft)	10	94	15	10	10	20	15	15	20	20
No. D (no./hole x holes/row)	1x76=76	18x9=162	2x40=80	2x39=78	1x62=62	1x62=62	2x49=98	5x19=95	18x9=162	1x76=76
Spent fuel-spent fuel spacing--w/DHLW (ft)	15	72	19	19	19	19	24	34.5	72	15
--w/o DHLW (ft)	-	68	10.5	11.5	-	-	-	29.5	68	-
Spent fuel--DHLW spacing (ft)	7.5	36	9.5	9.5	9.5	9.5	12	17.25	36	7.5
Drift spacing (ft)	126	748	261	255	204	204	322	358	734	126
Drift standoff--DHLW-access (ft)	85.0	87.5	72.25	68.0	68.0	68.0	71.5	71.5	87.5	85.0
--Spent fuel-access (ft)	92.5	123.5	81.75	77.5	77.5	77.5	83.5	88.75	123.5	92.5
Thermal Information										
Borehole wall										
Maximum temperature (°C)	224	235	225	229	203	197	235	234	234	224
Yr	15	16	16	16	19	21	16	17	20	15
1 m from borehole wall										
Maximum temperature (°C)	185	200	197	198	171	166	198	196	197	185
Yr	22	24	19	19	26	30	21	23	26	22
Access drift										
Temperature at 50-yr (°C)	47	50	51	50	51	51	52	53	45	47
Emplacement drift										
Maximum Temperature (°C)	121	50	124	135	124	114	128	123	122	111
Yr	50	50	50	50	50	50	40	50	50	50

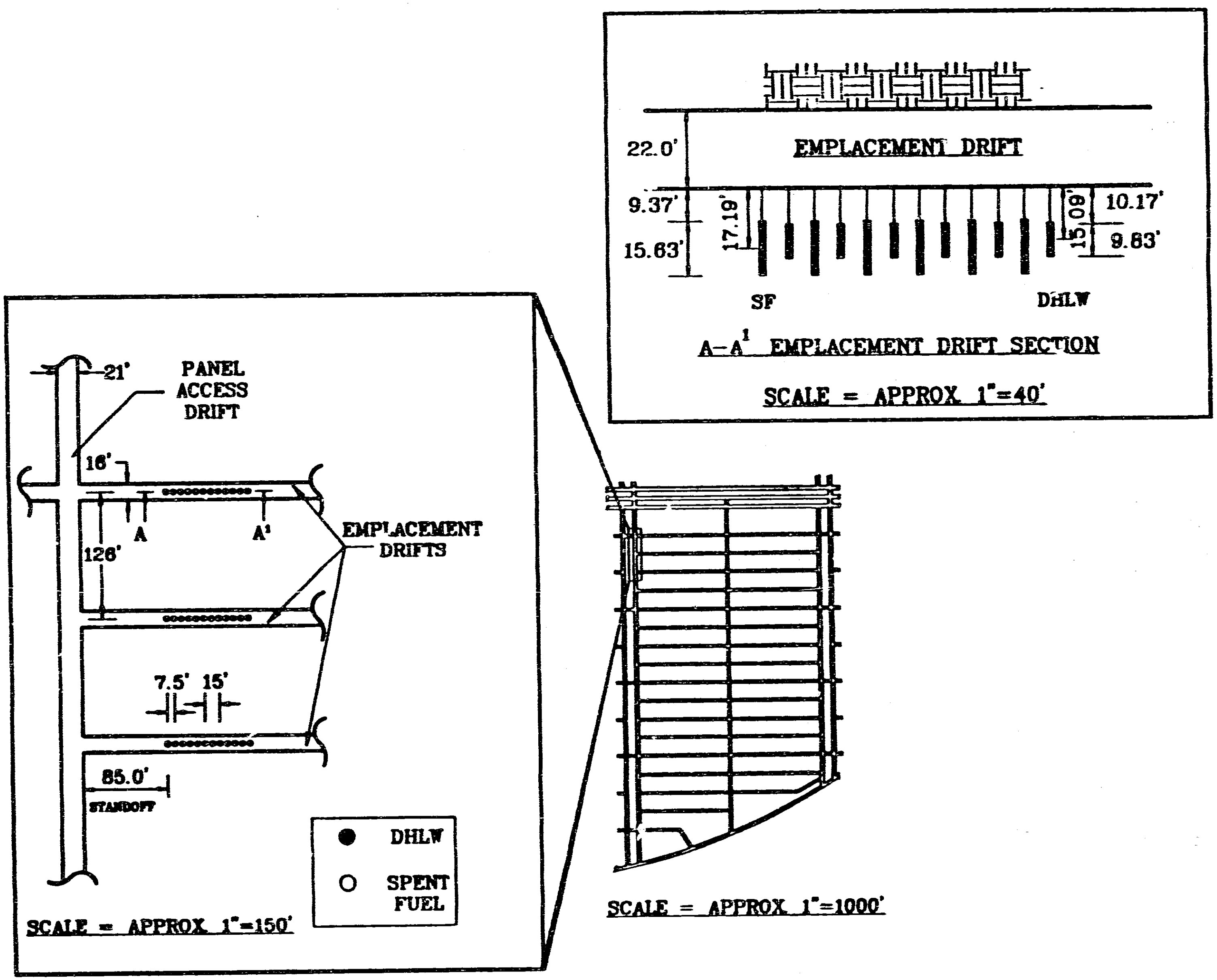

Figure 3-2. Vertical Case 1-V

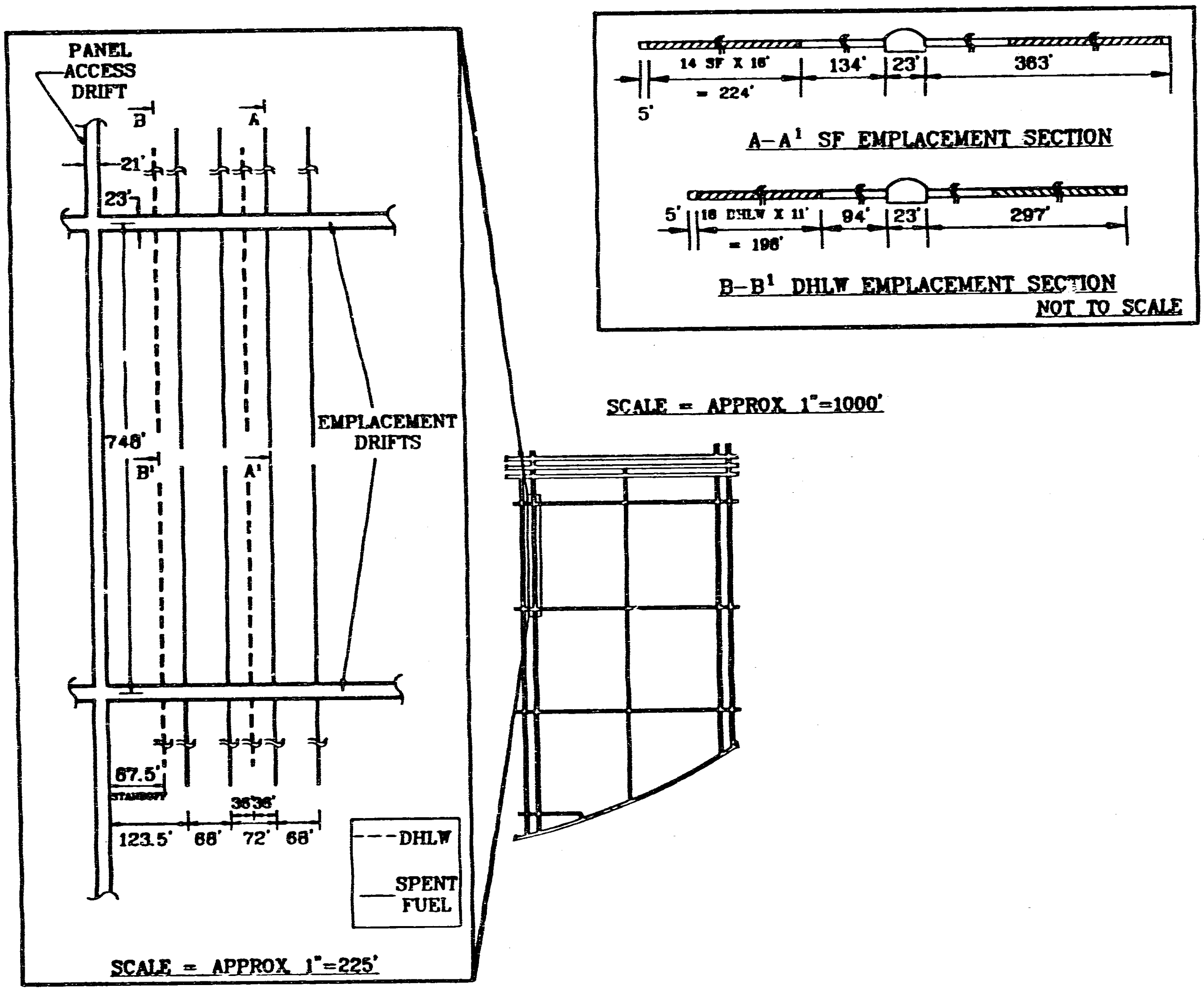

Figure 3-3. Horizontal Case 14-H

3.2.3 Short Horizontal Case 1-H

Case 1-H considers one spent fuel container in a 42-ft borehole or two DHLW containers in a 42-ft borehole. These lengths include a standoff of 20 ft for the spent fuel boreholes and 15 ft for the DHLW boreholes, measured from the waste container to the drift wall. A sequence of three boreholes (spent fuel, DHLW, spent fuel) is repeated along both sides of the emplacement drift (Figure 3-4).

Based upon thermal and physical constraints, the spacing between spent fuel containers is 19 ft when there is a DHLW container in between and 10.5 ft when there is no DHLW container in between. The emplacement drift spacing is 261 ft. Because the borehole spacing is limited by the minimum spacing constraint, the temperatures around the boreholes do not reach their allowable maximums.

3.2.4 Short Horizontal Case 1-HA

Case 1-HA considers one spent fuel container in a 32-ft borehole or two DHLW containers in a 37-ft borehole. These lengths include a standoff of 10 ft from the waste container to the drift wall. A sequence of three boreholes (spent fuel, DHLW, spent fuel) is repeated along both sides of the emplacement drift (Figure 3-5).

Based upon thermal and physical constraints, the spacing between spent fuel containers is 19 ft when there is a DHLW container in between and 11.5 ft when there is no DHLW container in between. The emplacement drift spacing is 255 ft. Because the borehole spacing is limited by the minimum spacing constraint, the temperatures around the borehole do not reach the allowable maximums.

3.2.5 Short Horizontal Case 1-HB

The layout for Case 1-HB is one spent fuel container in a 32-ft borehole alternating with one DHLW container in a 27-ft borehole. These

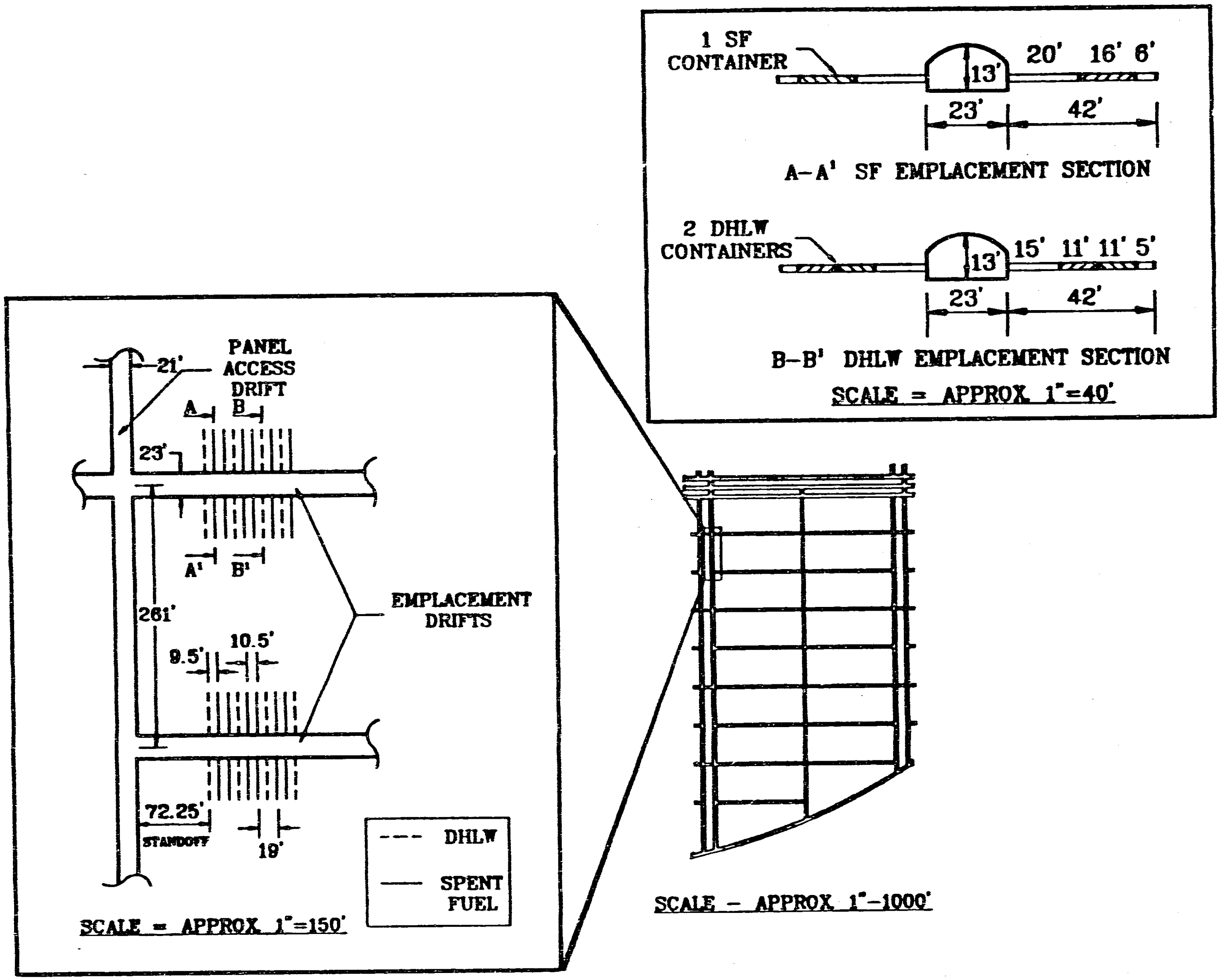

Figure 3-4. Short Horizontal Case 1-H

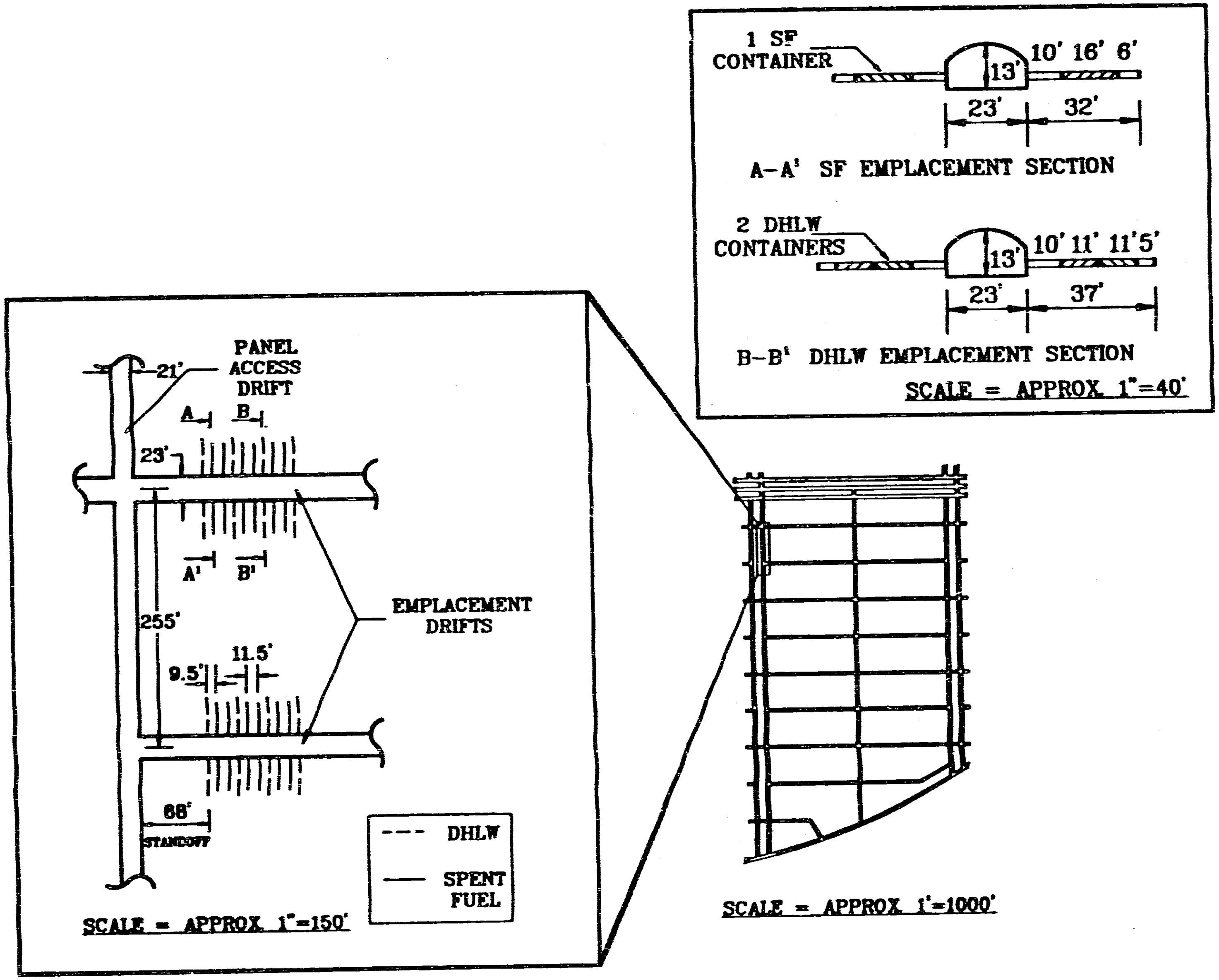

Figure 3-5. Short Horizontal Case 1-HA

lengths include a standoff of 10 ft from the waste container to the drift wall (Figure 3-6).

Based upon the minimum borehole spacing, the spacing between spent fuel containers is 19 ft and 9.5 ft between spent fuel and DHLW containers. The emplacement drift spacing is 204 ft. Because the borehole spacing is limited by the minimum spacing constraint, the temperatures around the borehole do not reach their allowable maximums.

3.2.6 Short Horizontal Case 1-HC

The layout for Case 1-HC considers one spent fuel container in a 42-ft borehole alternating with one DHLW container in a 37-ft borehole. These lengths include a standoff of 20 ft from the waste container to the drift wall (Figure 3-7).

Based upon the minimum borehole spacing, the spacing between spent fuel containers is 19 ft and 9.5 ft between spent fuel and DHLW containers. The emplacement drift spacing is 204 ft. Because the borehole spacing is limited by the minimum spacing constraint, the temperatures around the boreholes do not reach their allowable maximums.

3.2.7 Short Horizontal Case 2-H

Case 2-H considers two spent fuel containers in a 58-ft borehole alternating with two DHLW containers in a 42-ft borehole. These lengths include a standoff of 20 ft for the spent fuel borehole and 15 ft for the DHLW borehole, measured from the last waste container to the drift wall (Figure 3-8).

Based upon thermal constraints, the spacing between spent fuel boreholes is 24 ft and the emplacement drift spacing is 322 ft.

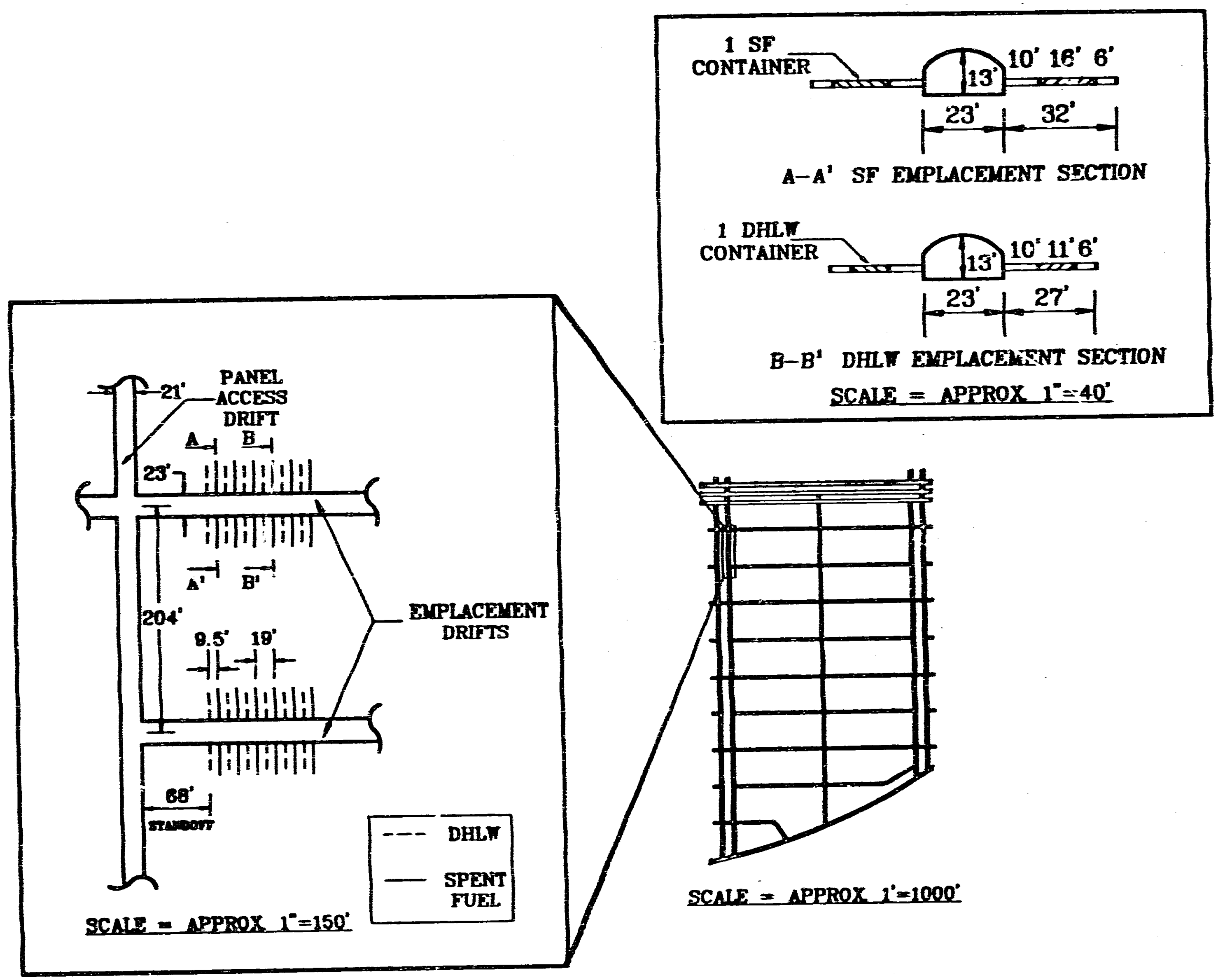

Figure 3-6. Short Horizontal Case 1-HB

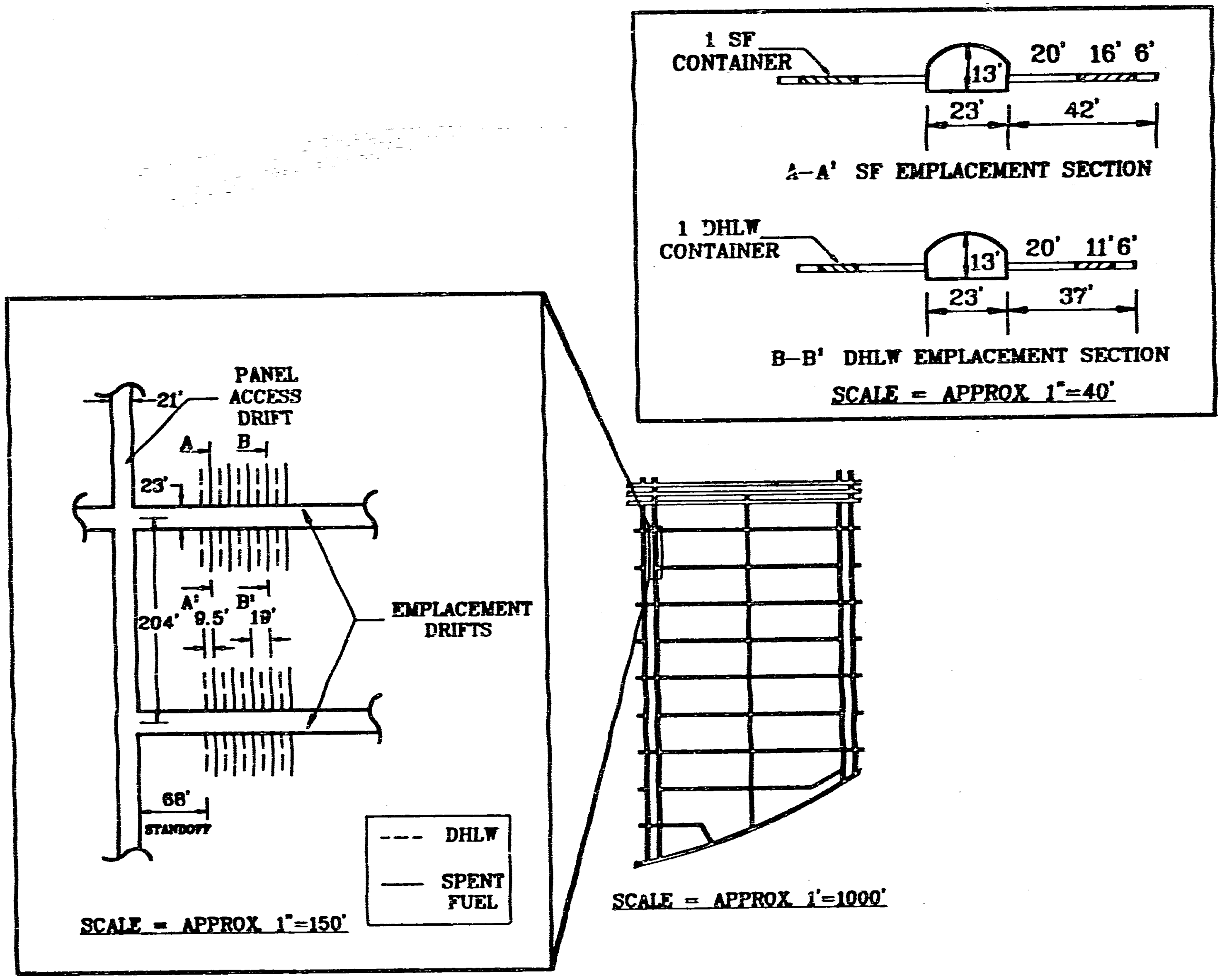

Figure 3-7. Short Horizontal Case 1-HC

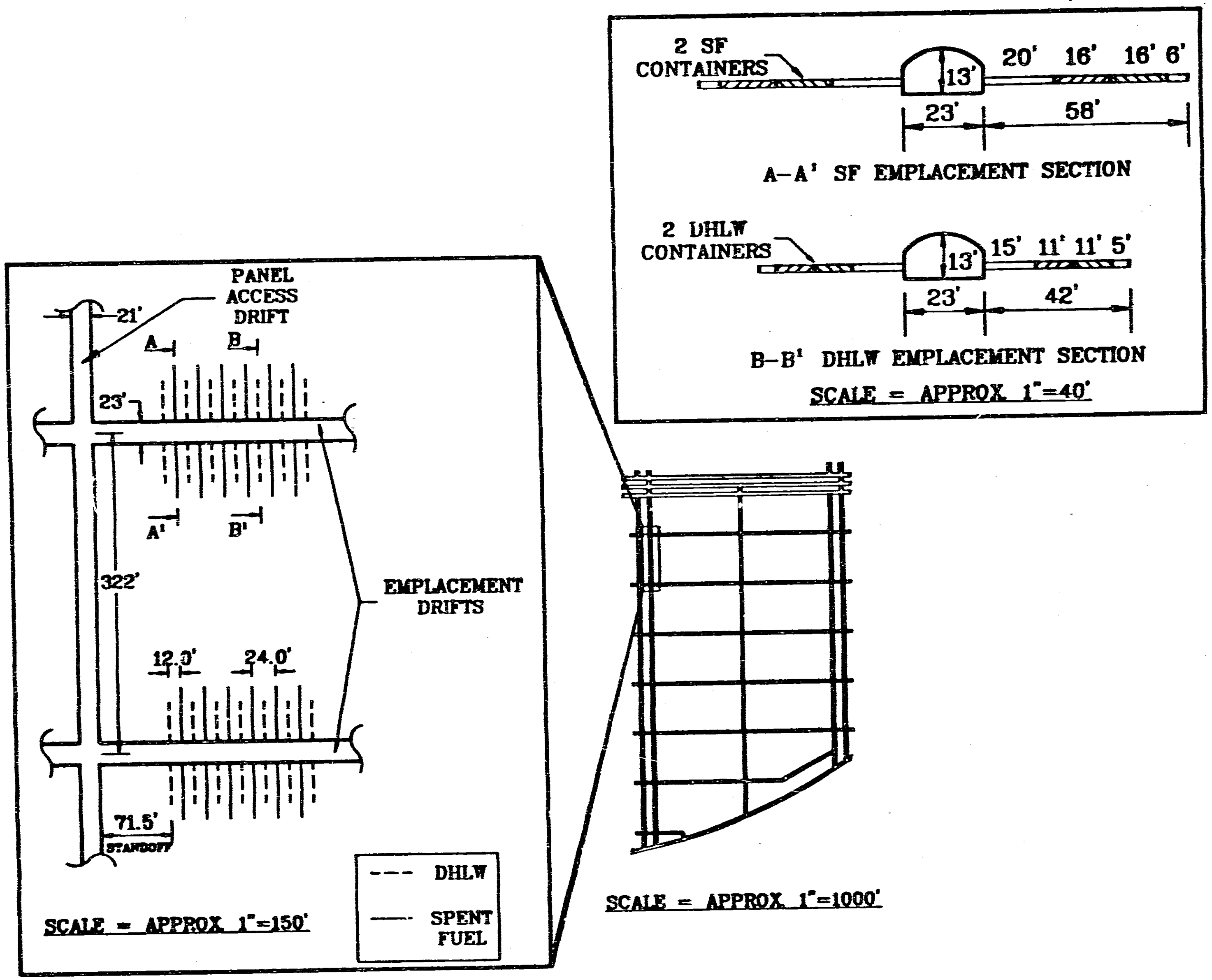

Figure 3-8. Short Horizontal Case 2-H

3.2.8 Short Horizontal Case 3-H

Case 3-H considers three spent fuel containers in a 75-ft borehole or five DHLW containers in a 75-ft borehole. These lengths include a standoff of 20 ft for the spent fuel boreholes and 15 ft for the DHLW boreholes, measured from the last waste container to the drift wall. A sequence of three boreholes (spent fuel, DHLW, spent fuel) is repeated along both sides of the emplacement drift (Figure 3-9).

Based upon thermal constraints, the spacing between boreholes containing spent fuel is 34.5 ft when there is a container of DHLW in between and 29.5 ft when there is no container of DHLW in between. The emplacement drift spacing is 358 ft.

3.2.9 Horizontal Case 14-HA

Case 14-HA considers 14 spent fuel containers in a 249-ft borehole and 18 DHLW containers in a 223-ft borehole. These lengths include a standoff of 20 ft from the waste container to the drift wall. A sequence of three boreholes (spent fuel, DHLW, spent fuel) is repeated along both sides of the emplacement drift (Figure 3-10).

Based upon thermal constraints, the spacing between boreholes containing spent fuel containers is 72 ft when there are containers of DHLW in between and 68 ft when there are no containers of DHLW in between. The emplacement drift spacing is 734 ft.

3.2.10 Vertical Case 1-VA

The layout for Case 1-VA considers one spent fuel container in a 35-ft borehole alternating with one DHLW container in a 30-ft borehole. These lengths include a standoff of about 20 ft from the waste container to the drift floor (Figure 3-11).

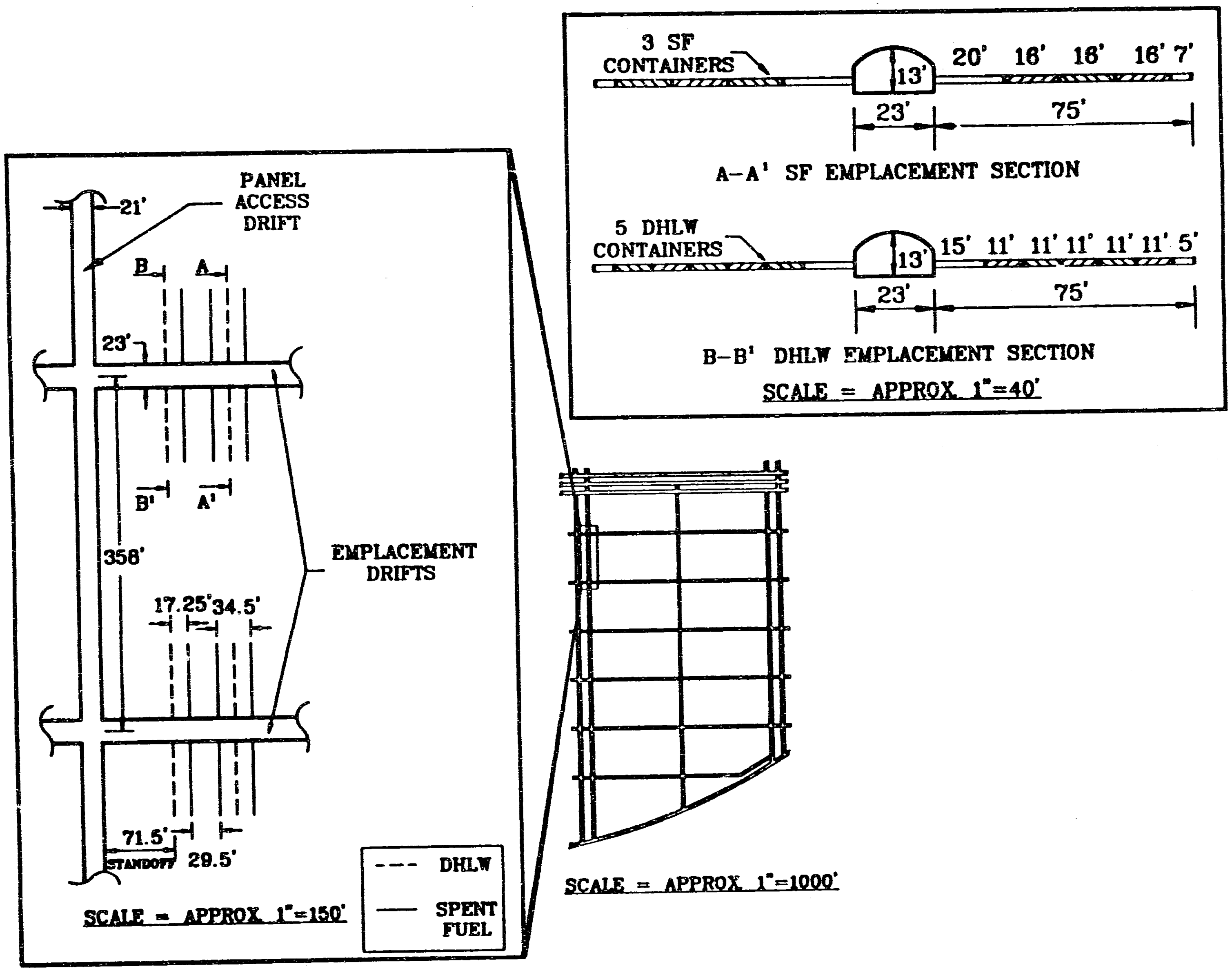

Figure 3-9. Short Horizontal Case 3-H

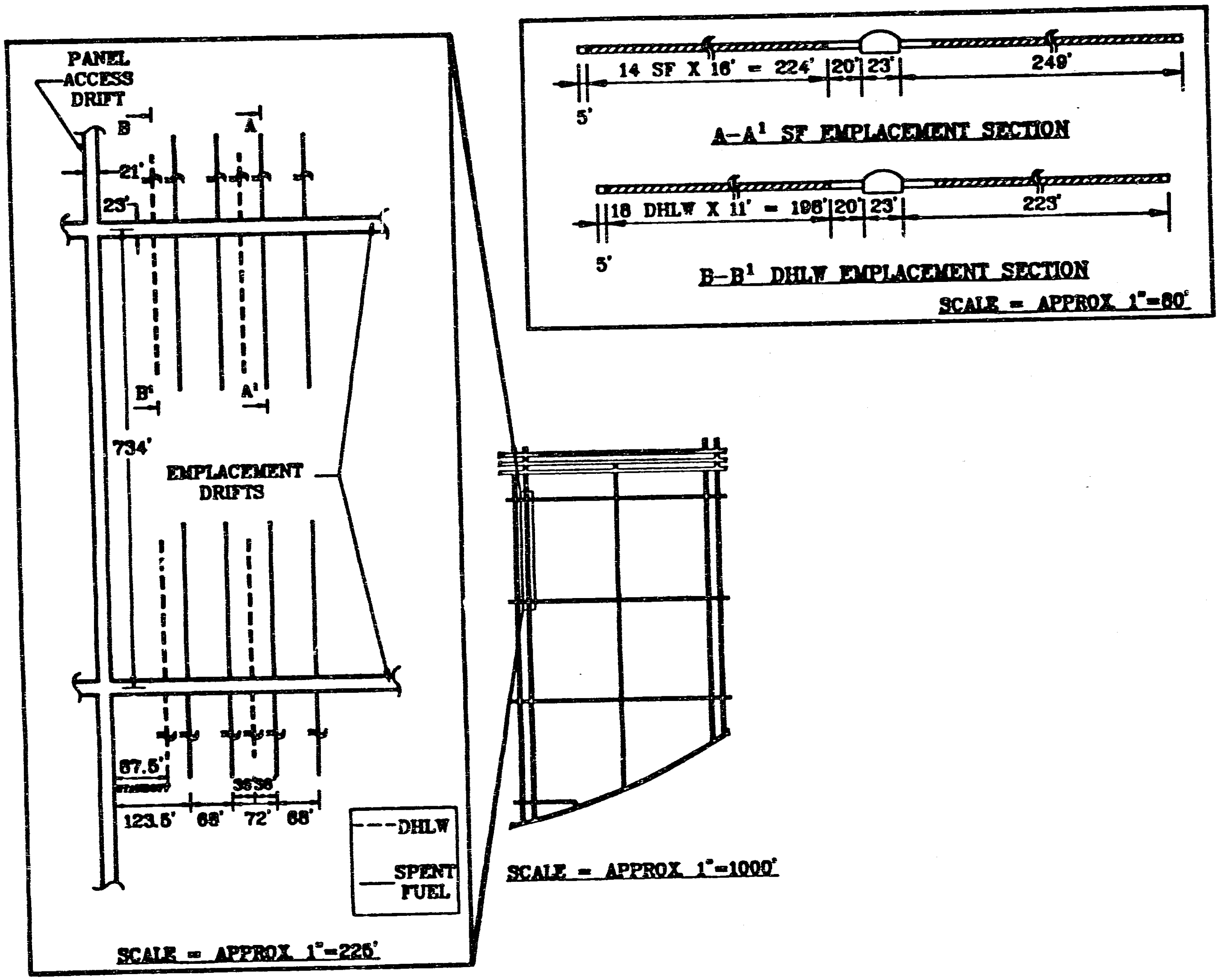

Figure 3-10. Horizontal Case 14-HA

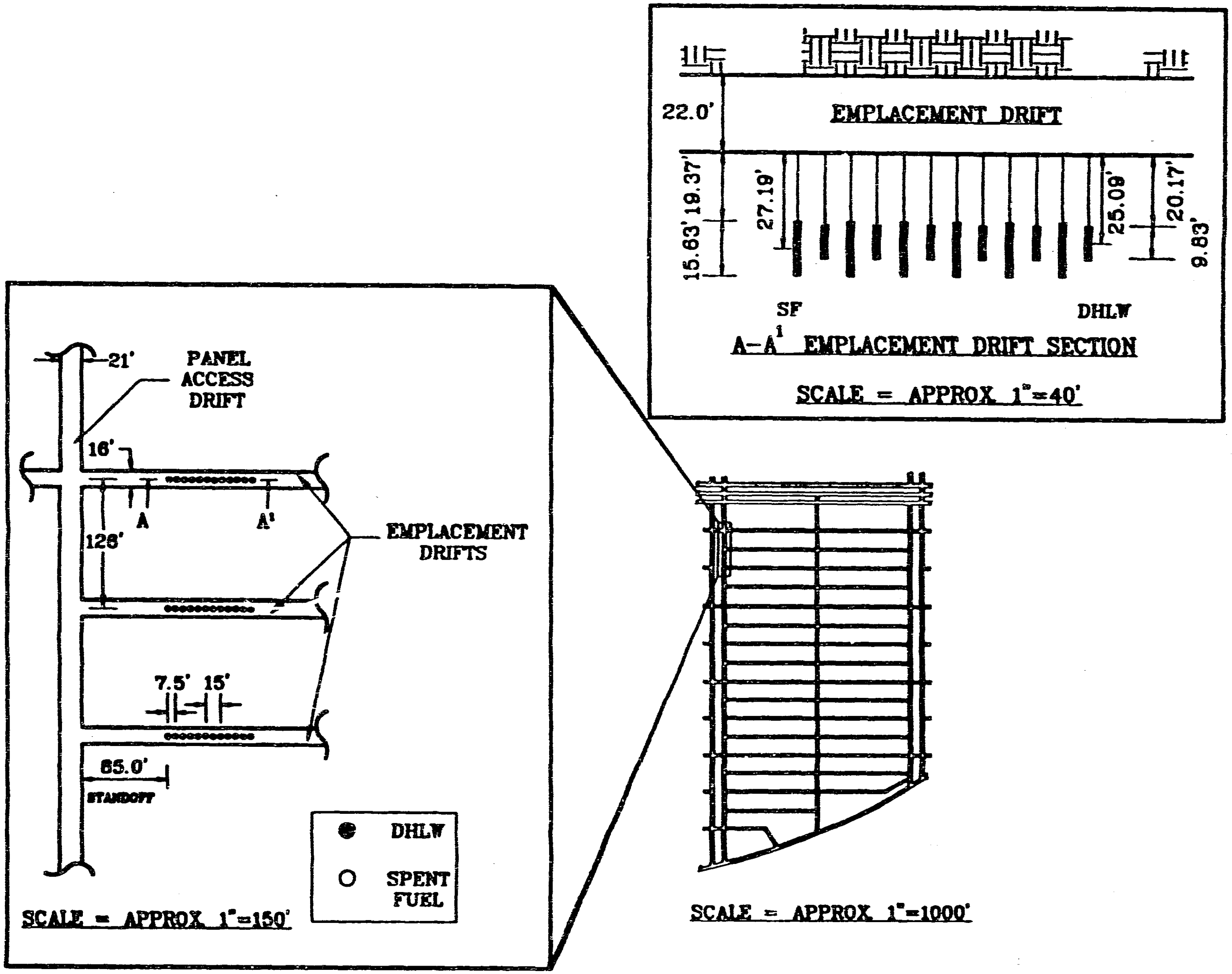

Figure 3-11. Vertical Case 1-VA

The spacing between boreholes containing spent fuel must be at least 7.5 ft and the emplacement drift spacing 126 ft (minimum borehole spacing). At this spacing the temperatures around the boreholes do not reach the allowable maximums.

3.3 Costs for Each Emplacement Option

The cost for SCP/CDR cases, referenced here as Case 1-V and Case 14-H, were reported and described in "Cost Estimate of the Yucca Mountain Repository Based on the Site Characterization Plan Conceptual Design" (Gruer, 1987). Only the costs for the subsurface facilities are relevant for this comparison because the other facilities are independent of emplacement borehole orientation. To show the portion of the total project costs which was included in subsurface facilities, Table 3-2 shows the cost for Case 1-V for the entire repository with the subsurface facilities identified by an asterisk. Note that the total subsurface costs amount to $2366.2 million, or about 36% of the total repository costs of $6597 million (all costs are reported in 1986 constant dollars). Table 3-3 lists subsurface facilities costs for Case 14-H.

Costs for each of the other options were calculated by modifying either the costs of Case 1-V or 14-H to reflect the changes in the borehole and drift configurations. Only costs affected by the configuration changes were recalculated using cost assumptions consistent with those used in the SCP/CDR cost estimates (Gruer, 1987). The results were tabulated and presented in Tables 3-4 through 3-11. The costs are reported in 1986 constant dollars.

TABLE 3-2

COST OF SUBSURFACE FACILITIES: CASE 1-V**
(millions of 1986 constant $)

Cost Account Title	Engineering and Construction	Operations	Closure and Decommissioning	Total
Management and integration	346.0	49.1	19.8	414.9
*Subtotal subsurface	89.2	1.7	13.4	104.3
Site preparation	167.4	114.0	37.8	319.2
*Site transport-subsurface		39.1		39.1
Waste handling facilities	488.0	1241.6	33.6	1763.2
WHB-1	101.6	--	--	101.6
WHB-2	342.6	--	--	342.6
Others	43.8	--	--	43.8
Balance of plant	85.7	1154.4	33.4	1273.5
*Surface shaft facilities	44.3	36.0	11.1	91.4
*Shafts/ramps	61.6	28.3	3.0	92.9
*Subsurface excavations	136.0	837.6	100.6	1074.2
Development drifting	89.3	375.1	12.8	477.3
Development boreholes	27.0	277.8	0.0	304.8
Emplacement/retrieval***	19.7	184.7	0.0	204.4
Backfill	0.0	0.0	87.7	87.7
*Subsurface service systems	88.5	744.3	131.6	964.4
Support systems	68.7	552.4	67.3	688.3
Utilities	8.9	47.8	50.6	107.3
Monitoring	10.9	144.1	13.7	168.7
Waste package fabrication	0.0	603.3		603.3
Total	1417.5	4808.6	370.9	6597.0
*Total for subsurface accounts only	419.6	1687.0	259.6	2366.2

*Costs associated with subsurface accounts only.
**One SF container in 25-ft vertical borehole and one DHLW container in 20-ft vertical borehole.
***Includes performance confirmation retrieval = 3.77.

TABLE 3-3

COST OF SUBSURFACE FACILITIES: CASE 14-H
(millions of 1986 constant $)

Cost Account Title	Engineering and Construction	Operations	Closure and Decommissioning	Total
Management and integration	75.9	1.3	4.7	81.9
Site transport	--	29.0	--	29.0
Surface shaft facilities	35.2	36.0	5.4	76.6
Shafts/ramps	60.1	28.3	0.7	89.1
Excavations	109.5	645.1	46.3	800.9
Drift development	70.2	188.0	4.3	262.5
Borehole development	18.7	259.3	0.0	278.1
Emplacement/retrieval*	20.6	197.8	0.0	218.4
Backfill	0.0	0.0	42.0	42.0
Service systems	76.3	553.3	27.0	656.6
Support systems	57.5	378.2	16.2	451.9
Utilities	7.8	30.9	3.7	42.4
Monitoring	10.9	144.1	7.1	162.1
Total costs of subsurface facilities	357.0	1293.0	84.1	1734.1

*Includes a removal cost of 24.35 for performance confirmation purposes.

TABLE 3-4

COST OF SUBSURFACE FACILITIES: CASE 1-H
(millions of 1986 constant $)

Cost Account Title	Engineering and Construction	Operations	Closure and Decommissioning	Total
Management and integration	101.6	2.0	8.6	112.2
Site transport	--	44.5	--	44.5
Surface shaft facilities	39.9	36.0	7.2	83.1
Shafts/ramps	60.7	28.3	1.7	90.7
Excavations	191.6	1153.4	65.6	1410.5
Drift development	76.9	251.5	5.9	334.3
Borehole development	93.3	617.9	0.0	711.2
Emplacement/retrieval*	21.3	284.0	0.0	305.3
Backfill	0.0	0.0	59.7	59.7
Service systems	78.9	604.1	85.0	767.9
Support systems	58.7	409.9	39.7	508.3
Utilities	8.9	47.8	37.1	93.9
Monitoring	11.3	146.4	8.1	165.8
Total costs of subsurface facilities	472.6	1868.3	168.1	2509.0

*Includes a removal cost of 4.44 for performance confirmation purposes.

TABLE 3-5

COST OF SUBSURFACE FACILITIES: CASE 1-HA
(millions of 1986 constant $)

Cost Account Title	Engineering and Construction	Operations	Closure and Decommissioning	Total
Management and integration	96.9	1.9	8.7	107.4
Site transport	--	42.7	--	42.7
Surface shaft facilities	40.1	36.0	7.2	83.3
Shafts/ramps	60.7	28.3	1.7	90.7
Excavations	175.6	1073.5	66.0	1315.1
Drift development	77.1	253.8	5.9	336.8
Borehole development	77.1	535.7	0.0	612.8
Emplacement/retrieval*	21.3	284.0	0.0	305.3
Backfill	0.0	0.0	60.1	60.1
Service systems	78.6	605.9	85.1	769.6
Support systems	58.4	411.7	39.5	509.6
Utilities	8.9	47.8	37.5	94.2
Monitoring	11.3	146.4	8.1	165.8
Total costs of subsurface facilities	451.9	1788.3	168.7	2408.8

*Includes a removal cost of 4.44 for performance confirmation purposes.

TABLE 3-6

COST OF SUBSURFACE FACILITIES: CASE 1-HB
(millions of 1986 constant $)

Cost Account Title	Engineering and Construction	Operations	Closure and Decommissioning	Total
Management and integration	103.5	2.1	9.1	114.6
Site transport	--	46.7	--	46.7
Surface shaft facilities	41.3	36.0	7.5	84.8
Shafts/ramps	60.7	28.3	1.7	90.7
Excavations	193.0	1211.3	70.8	1475.1
Drift development	79.0	277.7	6.7	363.4
Borehole development	92.7	608.7	0.0	701.4
Emplacement/retrieval*	21.3	324.9	0.0	346.2
Backfill	0.0	0.0	64.1	64.1
Service systems	80.3	626.6	87.5	794.5
Support systems	60.1	432.4	40.5	533.1
Utilities	8.9	47.8	38.8	95.6
Monitoring	11.3	146.4	8.1	165.8
Total cost of subsurface facilities	478.9	1950.9	176.6	2606.4

*Includes a removal cost of 4.44 for performance confirmation purposes.