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Experimental Assessment of the Thermal Performance of Storage Canister/Holding Fixture Configurations for the Los Alamos Nuclear Materials Storage Facility

John D. Bernardin
David C. Naffziger
William S. Gregory

Los Alamos
NATIONAL LABORATORY
Los Alamos, New Mexico 87545

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ABSTRACT

This report presents experimental results on the thermal performance of various nested canister configurations and canister holding fixtures to be used in the Los Alamos Nuclear Materials Storage Facility. The experiment consisted of placing a heated aluminum billet (to represent heat-generating nuclear material) inside curved- and flat-bottom canisters with and without holding plate fixtures and/or extended fin surfaces. Surface temperatures were measured at several locations on the aluminum billet, inner and outer cansisters, and the holding plate fixture to assess the effectiveness of the various configurations in removing and distributing the heat from the aluminum billet. Results indicated that the curved-bottom canisters, with or without holding fixtures, were extremely ineffective in extracting heat from the aluminum billet. The larger thermal contact area provided by the flat-bottom canisters compared with the curved-bottom design, greatly enhanced the heat removal process and lowered the temperature of the aluminum billet considerably. The addition of the fixture plates to the flat-bottom canister geometry greatly enhances the heat removal rates and lowers the canister operating temperatures considerably. Finally, the addition of extended fin surfaces to the outer flat-bottom canister positioned on a fixture plate, reduced the canister temperatures still further.

INTRODUCTION

The renovation of the Los Alamos Nuclear Materials Storage Facility (NMSF) calls for the long-term storage of heat-generating nuclear materials. A passive cooling scheme consisting of conduction, radiation, and free convection heat transfer, has been proposed to maintain the stored materials below acceptable temperature limits. In particular, the renovated facility will store the heat-generating material in nested stainless steel canisters, which in turn, are stored vertically within large steel pipes. The steel pipes are arranged in a linear array and dissipate the waste heat to a buoyancy-induced airflow.

The purpose of this study was, in part, to assess the thermal performances of two different canister designs, one with a concave bottom and one with a flat bottom. In addition, the enhanced heat removal benefits of two different canister holding fixture designs were investigated for both canister configurations. The experiment consisted of placing an aluminum billet, with an affixed electrical resistance heater to represent heat-generating nuclear material, inside curved- and flat-bottom canisters with and without holding plate fixtures and/or extended fin surfaces. Surface temperatures were measured at various locations on the aluminum billet, inner and outer canisters, and the holding plate fixture to assess the effectiveness of the various configurations in removing and distributing the heat from the aluminum billet.

EXPERIMENTAL METHODS

The NMSF single canister experimental apparatus, shown in Figure 1, was constructed to test the thermal performance of various storage canisters and holding

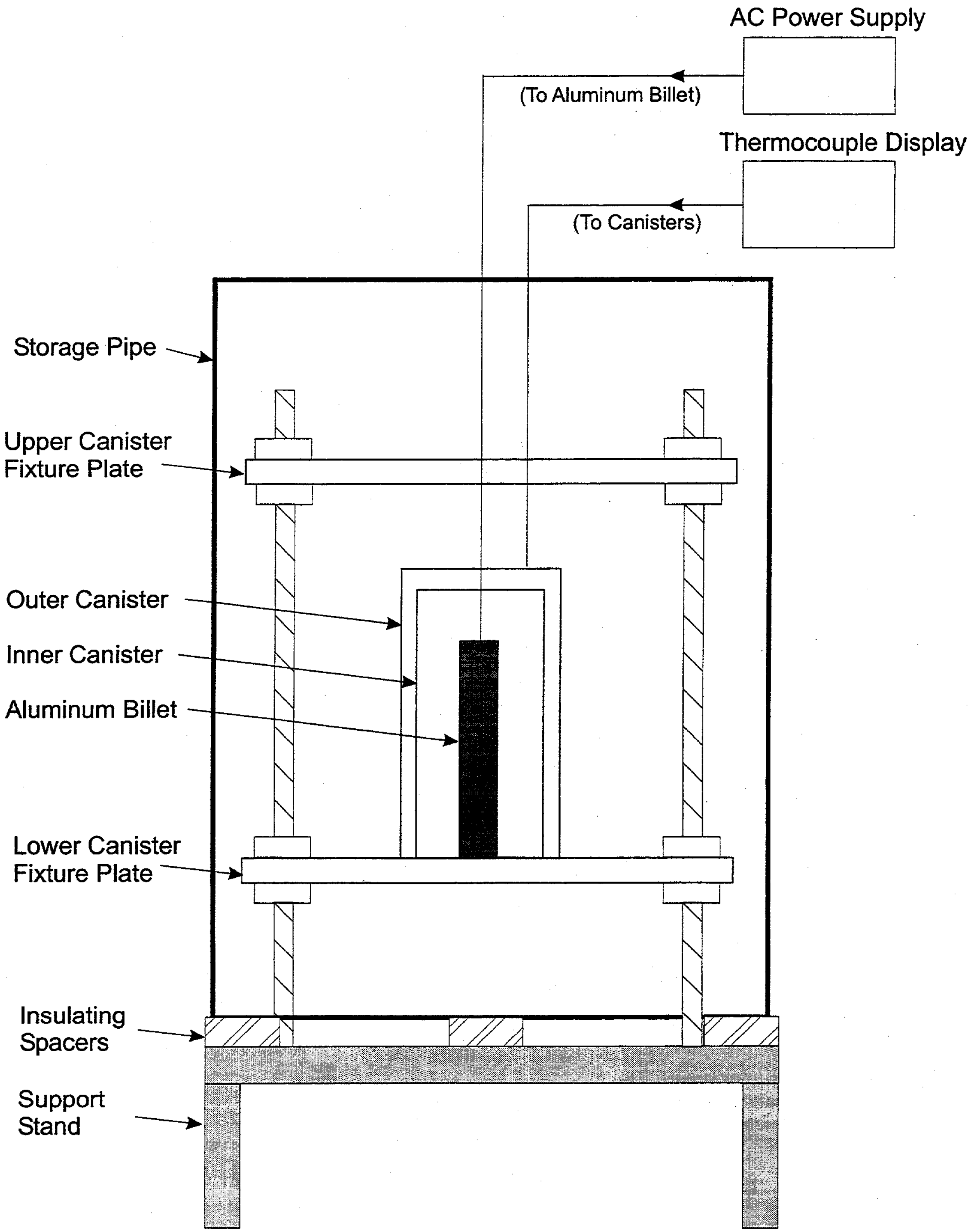
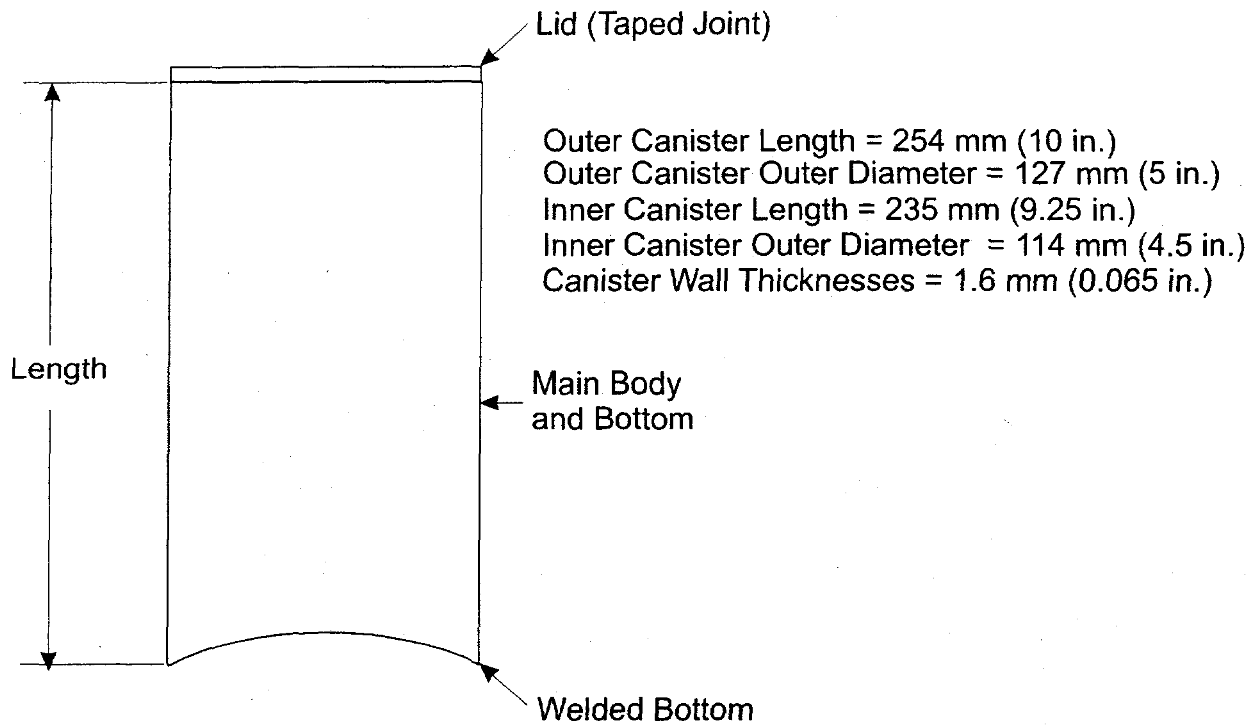


Figure 1. Schematic diagram of the NMSF single canister experimental heat transfer apparatus.

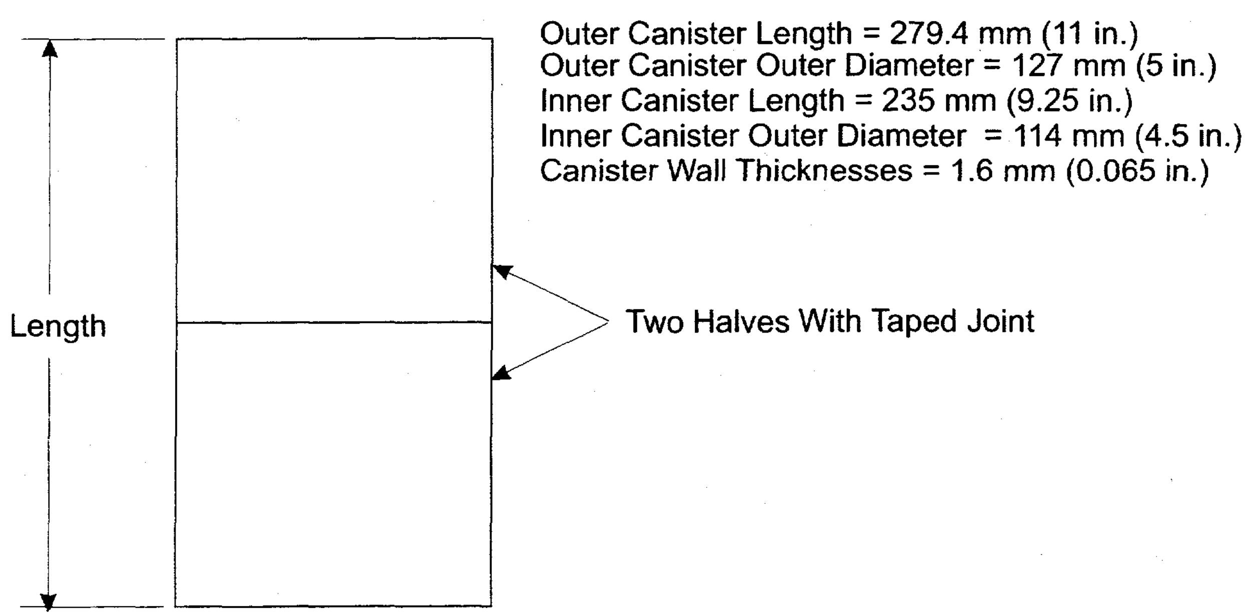
fixtures in a realistic geometry. The base of the facility consisted of a steel structure which supported a 0.610 m (2 ft) length of 0.457 m o.d. (18 in.) steel pipe. The nested canisters were placed within the steel pipe in one of two configurations. In the first configuration, which employed no canister holding fixture, the canister assembly was placed vertically on a thermally-insulated support stand. The insulating spacers prevented the support stand from interfering with the canister's thermal boundary layer. In the second configuration, the canister assembly was placed in thermal contact with an aluminum holding fixture as shown in Figure 1. A solid aluminum cylinder (length = 178 mm, diameter = 51 mm) containing an electrical resistance cartridge heater, was used to simulate heat-generating nuclear material. Power was supplied to the resistance heater by a variable ac voltage supply to produce steady-state heat dissipation rates of 10 W and 15 W. Type T thermocouples, connected to Omega DP462 temperature displays, were used to monitor material, canister, and holding fixture surface temperatures. The thermocouple locations are given in the experimental results section of this report.

Figures 2(a) and 2(b) display the two different canister geometries used in this study. Each configuration consisted of a set of two nested stainless steel canisters with the heat-generating aluminum cylinder placed inside the innermost canister. Small (6 mm) holes were drilled on the tops of the canisters to allow passage of the power and thermocouple leads. The lids of the curved-bottom cans and the two halves of the flat-bottom cans were taped in place to permit disassembly of the canister sets, as well as insertion and removal of the aluminum cylinder.

Two different fixture plate designs, a solid and a vented version shown in Figure 3, were used in several experimental runs to enhance canister heat extraction. The fixture



(a)



(b)

Figure 2. Schematic diagrams of the (a) curved-bottom and (b) flat-bottom canister geometries.

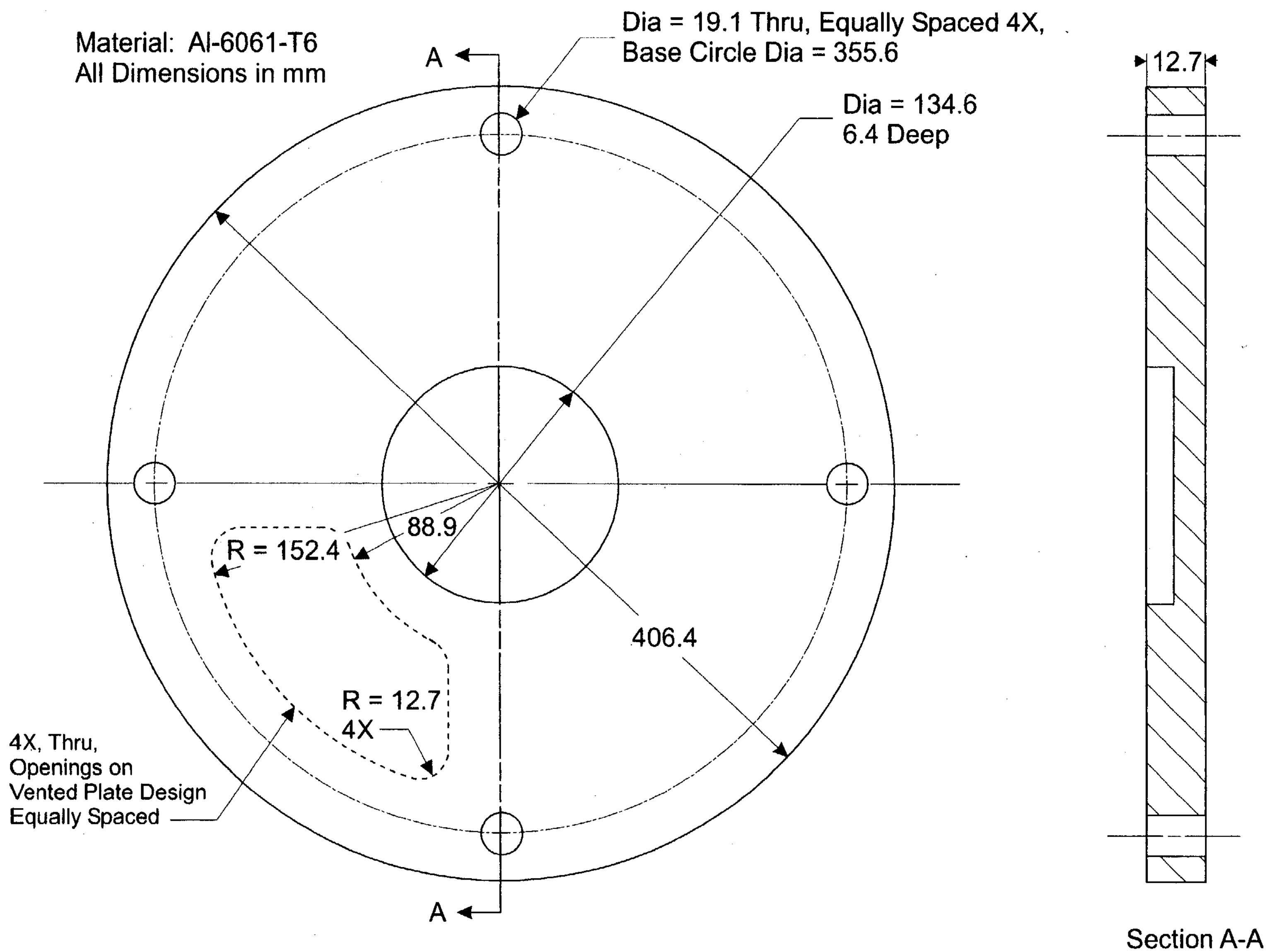


Figure 3. Schematic of the canister fixture plates.

plates were fabricated from aluminum 6061 and contained a 135 mm (5.30 in.) diameter and 6 mm (0.25 in.) deep recession to accept the canister bottom. The upper and lower fixture plates were fastened to four 19 mm (0.75 in.) threaded rods with a plate-to-plate spacing of 305 mm (12 in.).

In addition to the use of fixture plates, aluminum fins (thickness = 1.02 mm [0.04 in.], height = 279.4 mm [11 in.]) were attached in an equally-spaced vertical orientation to the outer surface of the flat-bottom canisters to increase the heat removal rate and lower the canister operating temperatures. Variations in the fin number (four to eight) and length (101.6 mm [4 in.] to 152.4 mm [6 in.]) were used to assess the heat transfer enhancements.

The experiments were initiated by placing the canister configuration inside the storage pipe and setting the voltage on the ac power supply to deliver the desired power output from the resistance heater (10 W or 15 W). Temperature measurements recorded at various time intervals indicated that approximately six hours were required to reach steady-state conditions. At this time, the final temperature distributions were recorded. This procedure was conducted for the various canister, fixture plate, and fin configurations. Several cases were repeated to ensure reproducibility.

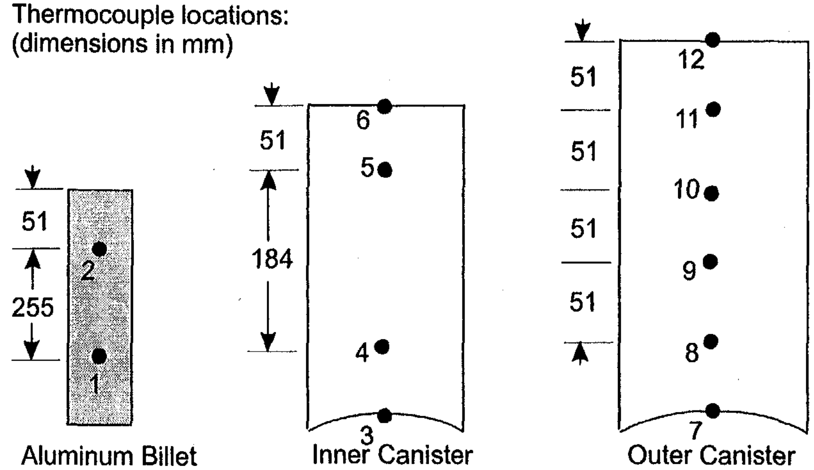
EXPERIMENTAL RESULTS

The experimental results are broken down into three categories. First, the temperature distributions for the curved-bottom and flat-bottom canisters are compared and discussed. Next, the heat transfer enhancements of the two different canister fixture plates are presented. Finally, the temperature reduction benefits of adding extended fin surfaces to the outer flat-bottom canister surface are detailed. A complete record of all experimental temperature data for these and other tests can be found in the Appendix to this report.

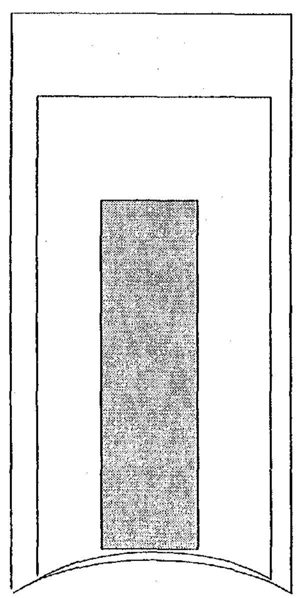
Canister Geometry

The thermocouple locations and corresponding temperature measurements for the curved-bottom and flat-bottom canisters without the canister holding fixture are displayed in Figures 4(a) and 4(b), respectively. For the curved-bottom canisters of Figure 4(a), steady-state temperatures are given for 10 W and 15 W of heat dissipation. It is clearly evident that for both power settings, the average aluminum billet temperature is considerably higher than the canister temperatures. The inner canister is hottest on the bottom surface due to direct contact with the aluminum. The buoyant convection heat transfer within the inner most canister is evident from the increase in surface temperature along the side of the canister from bottom to top. For 15 W of heat dissipation, the outer canister is at a fairly uniform temperature of approximately 42°C, which is roughly 30°C lower than the average temperature of the inner canister. The large temperature drop between the two canisters and the uniform temperature distribution on the outer canister are direct results of the poor thermal contact between the inner and outer canisters. These results indicate that the heat transfer from the outer canister's surface is fairly uniform for the curved-bottom canister when no holding fixture is utilized.

Figure 4(b) displays the thermocouple locations and corresponding temperature measurements for the flat-bottom canisters without the canister holding fixture. For a heat dissipation rate of 15 W, the temperature distribution for the flat-bottom canisters is

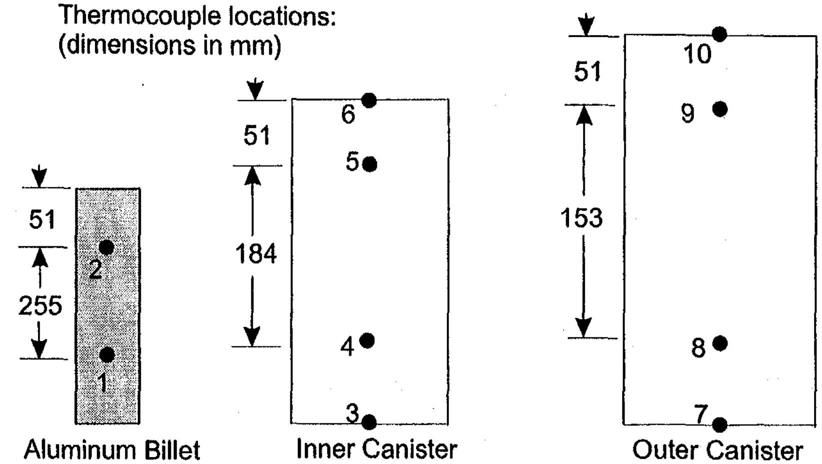


Nested Curved-Bottom Canisters:

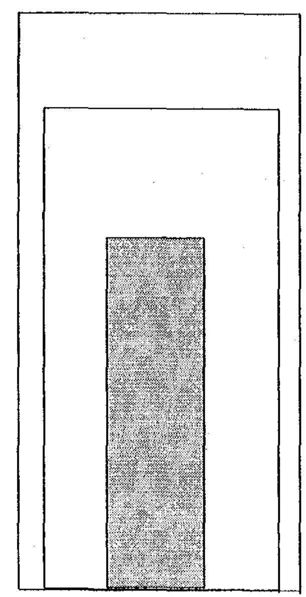


T.C. #	T [°C] (P = 10 W)	T [°C] (P = 15 W)
1	91.6	112.3
2	93.4	114.8
3	79.8	96.9
4	48.6	55.8
5	52.1	60.3
6	58.2	74.8
7	43.8	48.8
8	38.2	41.7
9	37.6	40.6
10	38.2	41.2
11	39.1	42.4
12	39.9	43.5

(a)



Nested Flat-Bottom Canisters:



T.C. #	T [°C] (P = 15 W)
1	82.1
2	88.8
3	60.6
4	45.1
5	44.1
6	53.8
7	64.2
8	44.4
9	39.1
10	35.6
11	NA
12	NA

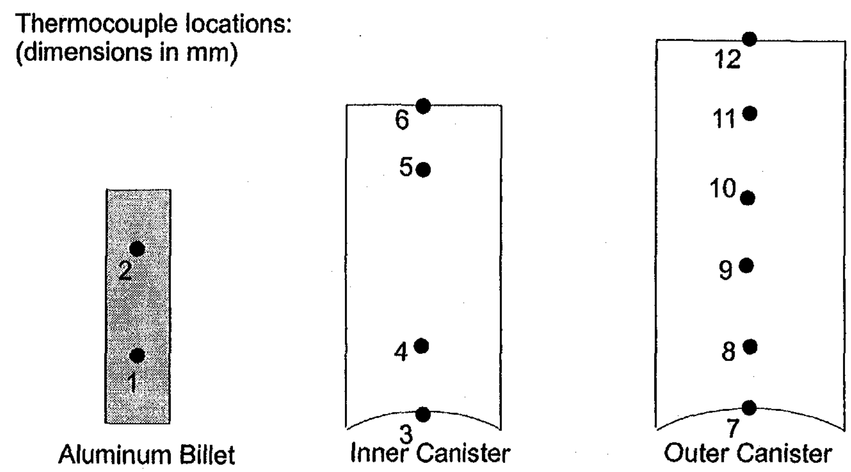
(b)

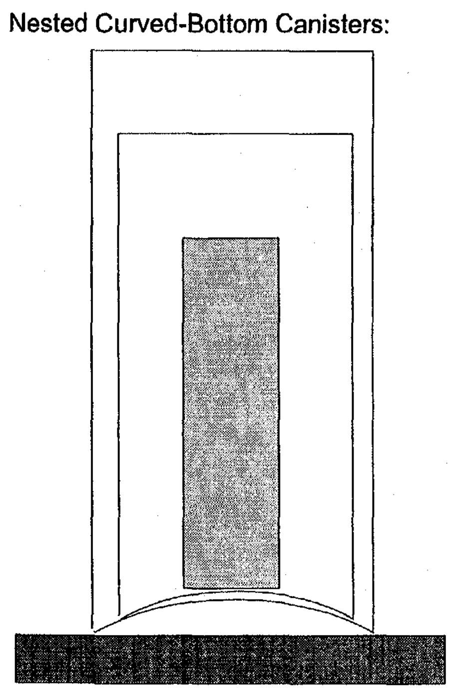
Figure 4. Thermocouple locations and temperature measurements for the nested (a) curved-bottom canisters and (b) flat-bottom canisters without a holding fixture plate.

significantly different from that of the curved-bottom canisters shown previously in Figure 4(a). First, the absolute temperature values for the flat-bottom arrangement are considerably lower than those for the curved-bottom design. For example, the average surface temperature of the aluminum billet in the flat-bottom canisters (86°C) is 28°C lower than that of the curved-bottom configuration (114°C). An additional difference in the two canister configurations can be seen in the temperature distributions on the outer canister surfaces. The uniform temperature distribution over the outer curved-bottom canister is not seen in the data of the flat-bottom design. The relatively large thermal contact area of the flat-bottom design provides a more efficient heat transfer path from the aluminum billet to the bottom of the canisters, resulting in a nearly 30°C temperature variation from the bottom to the top surface of the outer canister.

Canisters with Fixture Plates

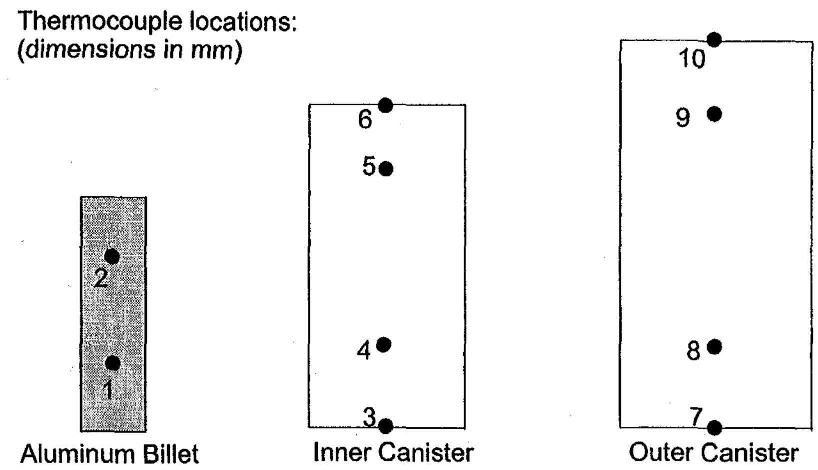
The heat transfer effects of the solid canister holding plate fixture are shown in Figures 5(a) and 5(b) for the curved-bottom and flat-bottom canisters, respectively, at a heat dissipation rate of 15 W. For the curved-bottom canister design, comparison of the temperature data of Figures 4(a) and 5(a) indicates that the addition of the fixture plate lowers the steady-state temperatures of the canisters and aluminum billet by only a few degrees and that the general temperature distribution pattern remains unchanged. This can be attributed to the poor thermal contact that existed between the outer canister and the fixture plate and indicates that less than 10% of the heat is dissipated by conduction from the outer canister to the fixture plate.

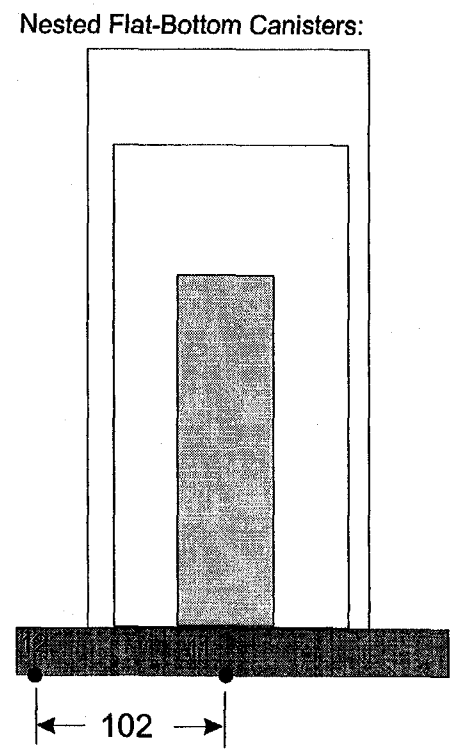




T.C. #	T [°C] (P = 15 W)
1	109.1
2	111.6
3	98.1
4	53.1
5	59.5
6	68.1
7	33.9
8	38.6
9	39.1
10	39.9
11	41.6
12	42.8

(a)





T.C. #	T [°C] (P = 10 W)	T [°C] (P = 15 W)
1	53.2	62.3
2	56.2	66.2
3	31.2	33.9
4	31.0	33.3
5	32.6	35.9
6	38.0	42.9
7		NA
8	30.1	32.2
9	30.9	34.0
10	30.3	32.7
11	29.6	31.9
12	28.2	30.3

(b)

Figure 5. Thermocouple locations and temperature measurements for the nested (a) curved-bottom canisters and (b) flat-bottom canisters on the solid fixture plate.

Addition of the solid canister holding plate fixture to the flat-bottom canister configuration provided substantial enhancements in the heat removal from the aluminum billet. In comparing the data in Figures 4(b) and 5(b), it is apparent that the average temperature of the aluminum billet dropped from 85°C to 64°C and the canister temperatures decreased approximately 10°C with the addition of the fixture plate. This can be attributed to the excellent thermal contact provided by the flat-bottom canisters and the heat dissipation area enhancement of the fixture plate. The temperature data of Figure 5(b) indicates that nearly isothermal conditions exist across the outer canister and fixture plate surfaces, and because the plate has roughly twice the surface area of the outer canister, nearly 66% of the heat is dissipated by the fixture plate.

Table 1 presents a comparison between the average canister and billet temperatures obtained with flat-bottom canisters positioned on the two different fixture plate designs. It is apparent from the data that, for a single canister, the plate geometry does not significantly influence the operating temperatures. It is speculated however, that for multiple canisters arranged in a vertical column, the fixture plate geometry will dictate canister operating temperatures by controlling the free convection airflow patterns.

Table 1. Comparison of average billet and canister surface temperatures for two different fixture plate geometries and a heat dissipation rate of 15 W.

Component Location	Temperature (°C) Solid Fixture Plate	Temperature (°C) Vented Fixture Plate
Billet	73.4	72.9
Inner Canister Top	46.0	45.5
Inner Canister Side	37.1	36.7
Outer Canister Top	33.5	33.0
Outer Canister Side	33.5	33.4

Canisters with Fins

Table 2 displays the average billet and canister temperatures for various fin configurations on a flat-bottom canister positioned on the vented fixture plate. Comparisons between the 'no fin' and 'four short fins' test cases show nearly identical temperature distributions within experimental error and thus no beneficial effect of the fins. This may be the result of high thermal contact resistance between the fins and the outer canister surface. The data for the eight fin configurations show outer canister temperatures that are approximately 1.5°C to 3°C less than those temperatures corresponding to the 'no fin' case. However, further inspection of the data for these cases reveals no clear trend in the temperature dependence of the billet on the fin area enhancement. For example, the slight rise in billet temperature and the corresponding decrease in outer canister surface temperature for the '8 short fins' test case in comparison with the 'no fin' test case, may be a result of inconsistent surface contact of the billet with the inner canister bottom between tests. Consequently, accurate assessment in the heat transfer enhancement of the fin configurations cannot be made at present.

Table 2. Comparison of average billet and canister surface temperatures for different fin configurations on a flat-bottom canister positioned on the vented fixture plate with a heat dissipation rate of 15 W.

Component Location	Temperature (°C)			
	No Fins	4 Short* Fins	8 Short Fins	4 Short Fins & 4 Long** Fins
Billet	72.9	76.9	77.2	72.9
Inner Canister Top	45.5	46.9	45.5	43.3
Inner Canister Side	36.7	37.9	36.1	34.5
Outer Canister Top	33.0	33.6	31.6	30.6
Outer Canister Side	33.4	33.8	31.2	30.3

* Short fin length = 101.6 mm (4 in.)
** Long fin length = 152.4 mm (6 in.)

Summary of Operating Temperatures for Various Canister, Plate, and Fin Configurations

A comprehensive summary of average billet and outer canister operating temperatures for the different canister, holding fixture, and fin designs is given in Table 3 (see Appendix for complete sets of data). Based upon this data, a ranking of the thermal performance of the various configurations in reducing the material temperature (an aluminum billet in this study) at a heat dissipation of 15 W, is from best-to-worst:

1. Flat-bottom canister with either the solid or vented fixture plate,
2. Flat-bottom canister without the fixture plate,
3. Curved-bottom canister with the fixture plate, and
4. Curved-bottom canister without the fixture plate.

The effectiveness of the fins was inconclusive from the current study and hence they were not given in the above ranking.

Table 3. Summary of average billet and outer canister surface temperatures for different canister, fixture plate, and fin configurations and heat dissipation rates of 10 W and 15 W.

Canister/Plate/Fin Configuration	Power (W)	Av. Billet Temp (°C)	Average Outer Canister Temp (°C) Top	Side	Bottom
Curved-bottom canister, no fixture plate	10 15	92.5 113.6	39.9 43.5	38.3 41.5	43.8 48.8
Curved-bottom canister, solid fixture plate	15	110.4	42.8	39.8	33.9
Flat-bottom canister, no fixture plate	15	85.5	35.6	41.8	64.2
Flat-bottom canister (Test #1), solid fixture plate	10 15	54.7 64.3	30.3 32.7	30.5 33.1	29.6 31.9
Flat-bottom canister (Test #2), solid fixture plate	10 15	57.4 73.4	29.6 33.5	29.7 33.5	26.9 29.3
Flat-bottom canister, vented fixture plate	10 15	55.9 72.9	29.4 33.0	29.7 33.4	26.9 28.2
Flat-bottom canister, vented fixture plate, and 4 fins equal length	15	76.9	33.6	33.8	32.6
Flat-bottom canister, vented fixture plate, and 8 fins equal length	15	77.2	31.6	31.2	27.9
Flat-bottom canister, vented fixture plate, and 8 fins, 4 extended	15	72.9	30.6	30.3	31.2

CONCLUSIONS

This study investigated the thermal performance of various storage canister/holding fixture configurations for the Los Alamos NMSF. From the results of this investigation, the following conclusions can be drawn.

1) The curved-bottom canister design did not provide an adequate thermal path between the heat-generating material and the environment and, consequently, resulted in relatively high billet temperatures.

2) The poor thermal contact of the curved-bottom canister created a nearly uniform temperature distribution on the outer canister surface and negated any beneficial heat transfer surface area enhancements of the canister holding plate fixture.

3) Relatively low billet temperatures were obtained with the flat-bottom canister design as a result of the good thermal contact between the heat-generating material and the canister bottoms.

4) The flat-bottom canisters provided excellent thermal contact between the aluminum billet and the canister holding plate fixture. Consequently, the additional heat dissipation surface area provided by the fixture plate significantly reduced the billet and canister operating temperatures. It was estimated that nearly 66% of the heat was dissipated through the fixture plate.

5) The vented and solid fixture plates had nearly identical effects on the thermal operating characteristics of the flat-bottom canister design. It is speculated that the fixture design will have a more significant effect in larger scale experiments that will employ multiple canisters/fixtures.

6) The addition of fins to the outer flat-bottom canister surface appeared to have a slightly beneficial effect in reducing operating temperatures. This lack of thermal optimization was believed to be the result of poor thermal contact between the fins and canister in the current prototype design. Enhanced heat dissipation should be realized by adding fins that use a more reliable mounting scheme.

Appendix - Experimental Data

(See Figures 4 and 5 for thermocouple locations corresponding to the thermocouple numbers in the following tables.)

Table A.1. Curved-bottom canisters without fixture plates.

Thermo-couple #	Temperature (°C) [P =10 W]	Temperature (°C) [P =15 W]
1	91.6	112.3
2	93.4	114.8
3	79.8	96.9
4	48.6	55.8
5	52.1	60.3
6	58.2	74.8
7	43.8	48.8
8	38.2	41.7
9	37.6	40.6
10	38.2	41.2
11	39.1	42.4
12	39.9	43.5

Table A.2. Curved-bottom canisters with solid fixture plates.

Thermo-couple #	Temperature (°C) [P =15 W]
1	109.1
2	111.6
3	98.1
4	53.1
5	59.5
6	68.1
7	33.9
8	38.6
9	39.1
10	39.9
11	41.6
12	42.8

Table A.3. Flat-bottom canisters with solid fixture plates.

Thermo-couple #	Temperature (°C) [P =15 W]
1	82.1
2	88.8
3	60.6
4	45.1
5	44.1
6	53.8
7	64.2
8	44.4
9	39.1
10	35.6
11	NA
12	NA

Table A.4. Flat-bottom canisters with solid fixture plates (run #1 — no tape residue contamination on bottom end of billet).

Thermo-couple #	Temperature (°C) [P =10 W]	Temperature (°C) [P =15 W]
1	53.2	62.3
2	56.2	66.2
3	31.2	33.9
4	31.0	33.3
5	32.6	35.9
6	38.0	42.9
7	NA	NA
8	30.1	32.2
9	30.9	34.0
10	30.3	32.7
11	29.6	31.9
12	28.2	30.3

Table A.5. Flat-bottom canisters with solid fixture plates (run #2 — tape residue contamination on bottom end of billet).

Thermo-couple #	Temperature (°C) [P =10 W]	Temperature (°C) [P =15 W]
1	56.6	72.2
2	58.1	74.5
3	29.7	33.4
4	30.4	34.6
5	33.7	39.5
6	38.1	46.0
7	23.0 (air)	23.2 (air)
8	29.0	32.4
9	30.3	34.6
10	39.6	33.5
11	26.9	29.3
12	27.9	31.0

Table A.6. Flat-bottom canisters with vented fixture plates (test with tape residue contamination on bottom end of billet).

Thermo-couple #	Temperature (°C) [P =10 W]	Temperature (°C) [P =15 W]
1	55.1	71.7
2	56.6	74.1
3	29.7	33.3
4	30.6	34.4
5	33.2	39.0
6	37.3	45.5
7	23.2 (air)	23.5 (air)
8	29.4	32.6
9	30.0	34.1
10	29.4	33.0
11	26.9	28.2
12	28.2	30.8

Table A.7. Flat-bottom canisters with solid top fixture plate and bottom vented fixture plate (test with tape residue contamination on bottom end of billet).

Thermo-couple #	Temperature (°C) [P =10 W]	Temperature (°C) [P =15 W]
1	55.8	72.2
2	57.3	74.5
3	30.6	33.7
4	31.3	34.4
5	34.2	39.4
6	38.2	45.9
7	23.7 (air)	23.1 (air)
8	29.9	32.3
9	31.1	34.5
10	30.4	33.3
11	27.4	28.1
12	29.3	30.7

Table A.8. Flat-bottom canisters with bottom solid fixture plate and no top plate (test with tape residue contamination on bottom end of billet).

Thermo-couple #	Temperature (°C) [P =10 W]
1	56.8
2	58.3
3	29.7
4	30.2
5	33.3
6	37.7
7	23.5 (air)
8	28.7
9	29.9
10	28.8
11	26.7
12	27.9

Table A.9. Flat-bottom canisters with solid fixture plates and billet insulated from canister bottom.

Thermo-couple #	Temperature (°C) [P =15 W]
1	113.1
2	115.6
3	34.2
4	27.7
5	52.9
6	64.1
7	24.4 (air)
8	35.9
9	43.7
10	42.1
11	27.0
12	28.1

Table A.10. Billet alone on flat plate.

Thermo-couple #	Temperature (°C) [P =15 W]
1	52.8
2	58.2
3	NA
4	NA
5	NA
6	NA
7	22.8 (air)
8	NA
9	NA
10	NA
11	27.2
12	29.8

Table A.11. Flat-bottom canisters with vented fixture plates and 4 short vertical fins (test with tape residue contamination on bottom end of billet).
Air temp = 26.7°C.

Thermo-couple #	Temperature (°C) [P =15 W]
1	75.8
2	78.0
3	37.4
4	35.6
5	40.1
6	46.9
7	31.8 (fin tip)
8	NA
9	33.8
10	33.6
11	32.6
12	30.5

Table A.12. Flat-bottom canisters with vented fixture plates and 8 short vertical fins (test with tape residue contamination on bottom end of billet).
Air temp = 26.2°C.

Thermo-couple #	Temperature (°C) [P =15 W]
1	76.1
2	78.3
3	39.9
4	34.3
5	37.9
6	45.5
7	30.1 (fin tip)
8	31.2
9	31.2
10	31.6
11	27.9
12	30.5

Table A.13. Flat-bottom canisters with vented fixture plates and 8 vertical fins, 4 short and 4 long (test with tape residue contamination on bottom end of billet). Air temp = 26.5°C.

Thermo-couple #	Temperature (°C) [P =15 W]
1	71.9
2	73.9
3	34.3
4	32.6
5	36.3
6	43.3
7	27.5 (fin tip)
8	30.3
9	30.3
10	30.6
11	31.2
12	28.0