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CONTENTS

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Frank E. Adcock

Abstract. Fiberboard-insulated fissile material containers of 10- and 30-gallon sizes have been tested at varying internal heat loads up to 20-watts. Temperature distribution throughout the packages is presented in graphical form. Highest containment vessel temperatures were 155°F for the 10-gallon package with a load of 10-watts and 148°F for the 30-gallon size with a load of 20-watts. Equilibrium temperature is reached approximately 24 hours after packaging with 80% of the temperature rise occurring during the first 10 hours.

INTRODUCTION

The Problem.

Radioactive materials are shipped in accordance with strict AEC and Department of Transportation (DOT) regulations. Safety for life and property is of prime consideration; damage-free transit of the product is not covered by the transportation standards.

Plutonium containers normally consist of a strong, steel-containment vessel (inner container) surrounded by insulation, and a light steel outside container. The insulation provides protection for the inner container and its seals so that no leakage will occur during or after an accidental fire (one of the required tests for a radioactive material container).

The radioactive decay of plutonium-239 results in about 2-watts of heat per kilogram of metal. This self-heating property of plutonium combined with the insulating properties of the containers could be expected to cause high internal package temperatures, resulting in three problems:

1. Damage to seals and gaskets.

2. Thermal hazard for shipping personnel.

3. Induced thermal stress in machined plutonium parts.

The last problem is one of product damage, not safety, and is beyond the scope of this paper.

Test Objective.

This study was conducted to determine container temperatures at various heating loads up to 20-watts.

Measurements were made on two types of containers, the Model 2030-1 (a 30-gallon container), and a DOT-6M container of 10-gallon size.

Plutonium was used to produce heating values of up to 10-watts. At higher heating loads, criticality considerations necessitated the use of electrical heating elements.

MODEL 1518 CONTAINER (DOT-6M)

Background.

Special Permit 5000 was the original DOT authorization for the Model 1518 Container. The 8-watt thermal decay energy limitation given in S.P. 5000 was sufficient for most shipments. The 8-watt value was found to be safe by determining actual container temperatures while loaded with plutonium. Prior to making the Model 1518 a DOT specification container, a utility review was conducted. As a result of this review, Rocky Flats was asked to determine a maximum practical limit on thermal decay energy. The tests described below were run in the spring of 1968 to provide the DOT with this limit.

Description of Container.

The Model 1518 container (Figure 1) has a nominal size of 15-inches diameter and 18-inches high and uses a 10-gallon steel drum for the outside skin. The inside container is constructed from steel tubing of 4.180-inches inside diameter; weight is 16-pounds, including the pipe plug closure. Details of the Model 1518 construction, testing, and early work on heat build-up are reported in RFP-1042.*

*F. E. Adcock and W. F. Wackler, "RFD Container-Model 1518 For Fissile Class II and Class III Shipments," RFP-1042, Rocky Flats Division, The Dow Chemical Company, April 8, 1968.

Figure 1. Model 1518 (DOT-6M) Container Showing Components and Sealed Food Cans Containing Plutonium Buttons.

Experiment.

Plutonium alloy fuel elements were used as the heat source. These were packaged in sealed food cans of 3.75-inches in diameter and heights up to 11-inches.

Runs were made at three levels of heating. The highest heat source used was approximately the equivalent of 4.5 kilograms of plutonium-239, which was the single package criticality limit.

Food cans in the containment vessel were cushioned with steel wool in accordance with standard shipping practice at Rocky Flats. The steel wool is also a good heat conductor and tends to equalize temperatures throughout the containment vessel.

Maximum food-can temperatures were determined using temperature sensitive pellets in the range of 100-275°F in 25° increments. Containment vessel temperatures were continuously monitored using a Foxboro six-channel recorder and three thermocouples; one placed on the top, one on the bottom, and one on the side of the vessel.

Room temperature remained at approximately 70°F throughout the experiment; however, no continuous recordings were made.

Results.

Figure 2 shows maximum food can and containment vessel temperatures plotted against heating value. Maximum temperatures of 155°F and 200°F were recorded on the containment vessel and food can at an energy level of 10.1 watts. The heating value was calculated using the actual isotopic content and the following data.**

Isotope	Heating Value (watts/kg)
239	1.9
240	7.1
241	3.6
242	0.1

**F. L. Oetting, "The Half-Life of Plutonium-239 by Calorimetry," *Plutonium 1970*, p. 154.

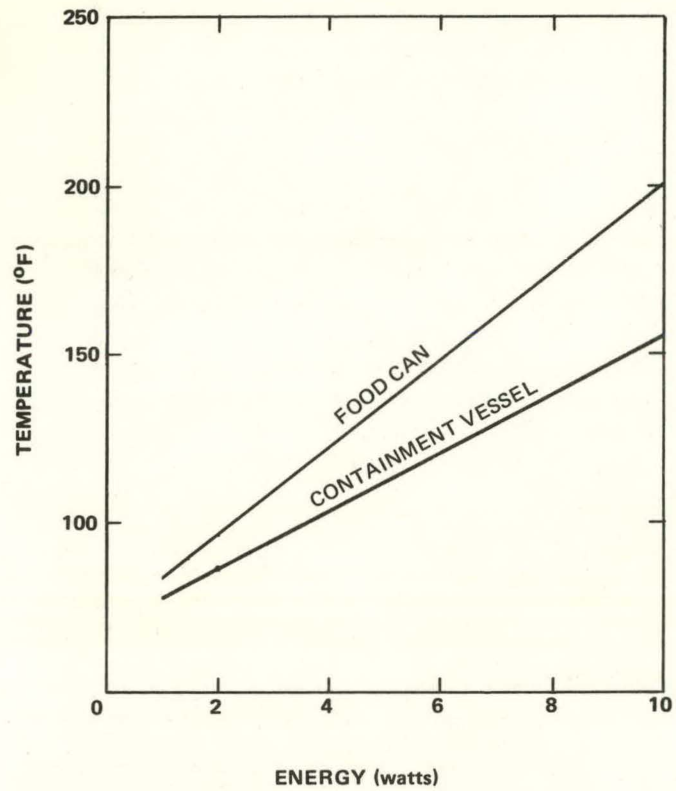


Figure 2. Results of Model 1518 Heat Build-up Study.

Discussion.

Based on the above results, DOT Specification 6M sets a 10.0-watt thermal decay heat limitation. This is a practical upper limit and is compatible with the single package criticality limit of 4.5 kilograms of plutonium-239. Sealed food cans containing plastic packaging will function satisfactorily up to at least 300°F without rupture or permanent deformation. In-plant handling of containment vessels and food cans would not present a hazard, but the use of cotton gloves or tongs is recommended.

If only actual transportation hazard is considered, a much higher heat limitation is possible. Even at 20-watts, the container (drum) skin temperature will be only a few degrees above ambient.

MODEL 2030-1 (DOT S.P.5332)

Background.

The Model 2030-1 container was originally designed in 1967 to provide a means of shipping plutonium metal in existing stainless steel storage vessels. Since that time, the container has found wide acceptance. Several hundred containers are in use by at least four major AEC Contractors.

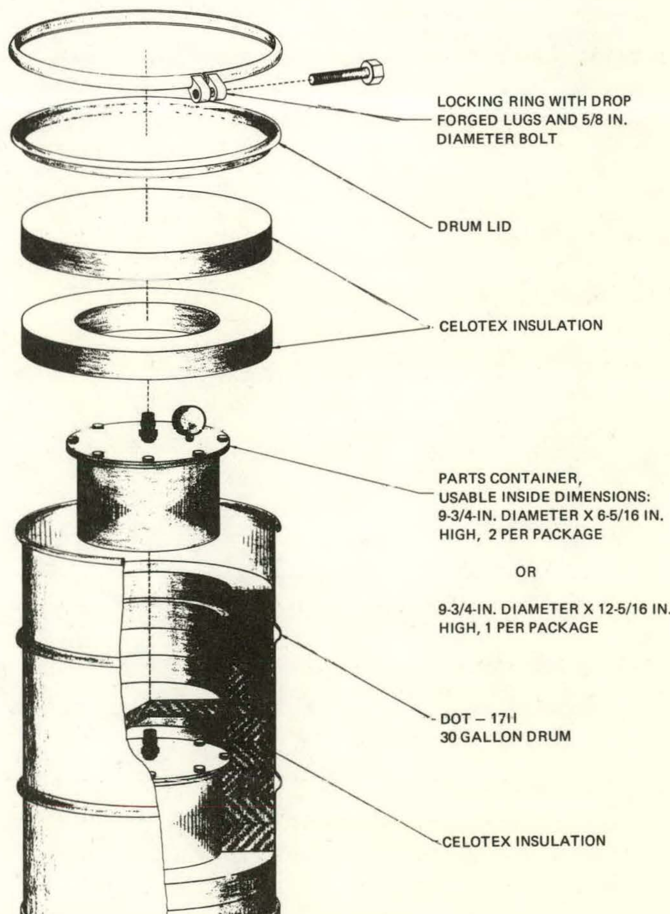
Description of Container.

The Model 2030-1 uses a 30-gallon drum 20-inches in diameter and 30-inches high. There may be two inner steel containers of 10-inch diameter as shown in Figure 3, or one longer container of identical construction. The drawing set for the Model 2030-1 is listed in the AEC's Engineering Materials List, TID-4100, reference number CAPE-1657.

Experiment.

Figure 4 shows a typical test setup. Three Hewlett-Packard two-channel recorders, Model 7100B, were used to make a continuous record of temperatures at four locations within the package. Room temperature and outside drum

Figure 3. Exploded View of Model 2030-1 Container.



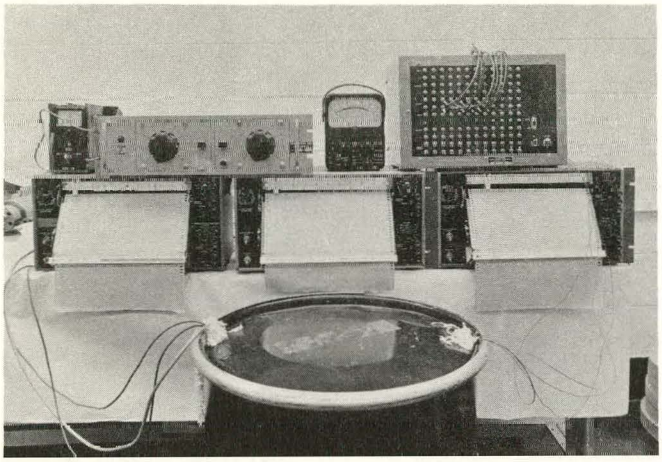


Figure 4. Typical Test Set-up Showing Temperature Recorders and Container.

temperature were recorded at intervals throughout the experiment. The rheostats shown in Figure 4 were used to control the input to 10-ohm heating elements. Containment vessel, food can, heating element, and metal-foil packing are shown in Figure 5.

Five runs were made with the entire load within one inner container. Two runs used plutonium-239 buttons individually sealed in food cans $4^1/_{16}$-inches in diameter and $4^1/_{16}$-inches high. By using one or two buttons, heating values of approximately 5- and 10-watts were obtained. Three more runs were made using a heating element inside a food can with heating values of 10-, 15-, and 20-watts.

Results.

The graphic portion of Figure 6 shows the results of five runs, all corrected to correspond to a room temperature of 70°F. Even at 20-watts of heating, which is double

Figure 5. Inner Container and Lid, Food Can, Heating Element, and Metal-Foil Packing.

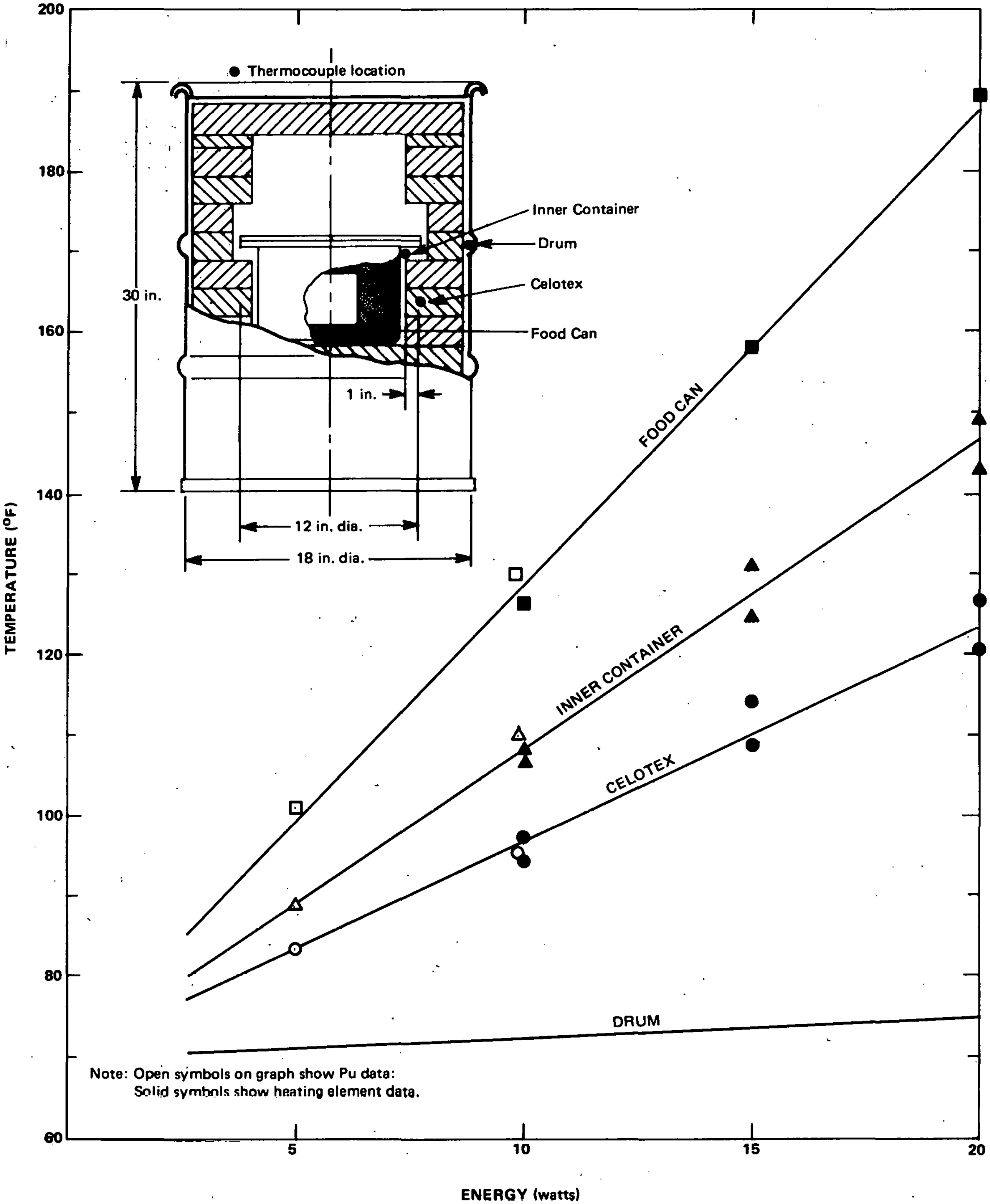
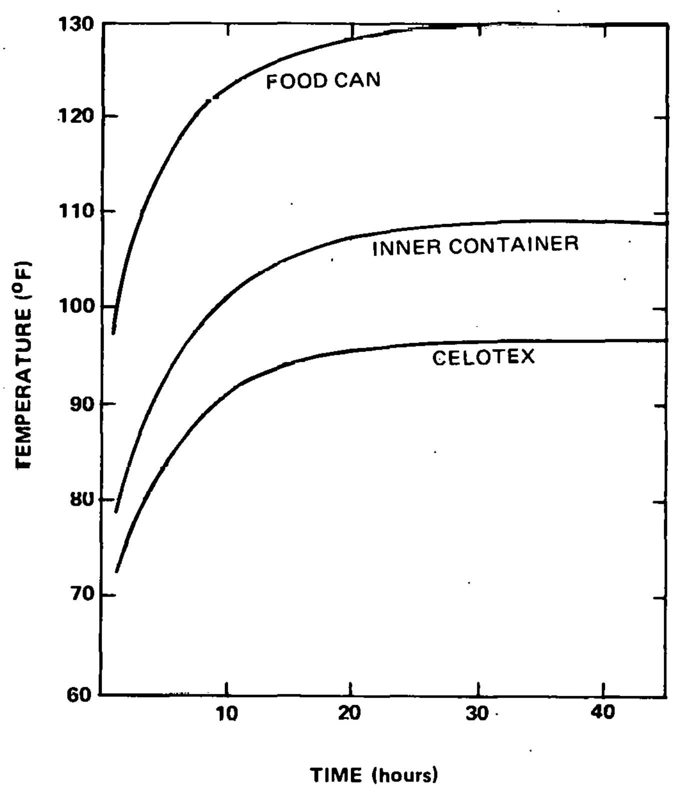


Figure 6. Results of Model 2030-1 Heat Build-up Study.

that resulting from the criticality limit of 5.0 kgs of plutonium-239, the inner container temperature of 147°F and the drum temperature of 75°F would not cause a handling or transportation problem.

Figure 7 shows that temperatures throughout the container reach equilibrium about 24 hours after packaging with 80% of the temperature rise occurring during the first 10 hours.

Figure 7. Typical Time-Temperature Curve With 10-watt Heat Source.



Recommendations.

Based on the results of this experiment, a heat limitation of 20-watts is recommended as a safe and practical limit. The fissile material may be in one containment vessel or divided in any manner between two vessels (unless criticality considerations dictate otherwise).

Calculations.

Once temperature measurements have been made for a particular container at one heat load, temperatures can be calculated for other heat loads or different ambient conditions. These calculations are valid only within the range of temperatures studied in this experiment where heat transfer by radiation is not significant.

$$Q = UA\Delta T \qquad (1)$$

Where:

Q = Rate of heat transfer (Btu/hr)

U = Overall coefficient of heat transfer (Btu/ft²-hr-°F)

T = Temperature (°F)

A = Surface area (ft²)

Using the data for one run at Q = 10 watts:

Q = 10 watts = 34.2 Btu/hr.

$T_{inner\ container} = 109°F$

$T_{room} = 70°F$

From equation (1):

$$UA = \frac{Q}{\Delta T} = \frac{34.2}{109-70} = 0.88 \qquad (2)$$

To calculate the temperature of the containment vessel for Q = 20 watts using equation (1) and the value for UA previously determined:

Q = 20 watts = 68.4 Btu/hr

UA = 0.88 Btu/hr-°F

$T_{room} = 70°F$

$$T_{inner\ container} = \frac{Q}{UA} + T_{drum}$$

$$= \frac{68.4}{0.88} + 78$$

$$= 148°F$$

This value compares very closely with the experimental value of 147°F as given in Figure 6.

OTHER CONSIDERATIONS

In addition to the variables studied in this experiment, several other factors will affect package temperatures:

- External exposure to direct sunlight or other heat
- Change in effective insulation by varying the thickness or the "K" factor.
- Variations in container design, such as size, mass, air gaps, and other factors that would affect the heat transfer properties of the package.

Each user must assess his own container design and expected transportation environment to estimate the resulting package temperatures.