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OPERATIONAL FACETS OF A DRY SPENT FUEL CASK

R. T. ANDERSON

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MASTER

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ROBERT T. ANDERSON
PAUL N. McCREERY
ALLIED-GENERAL NUCLEAR SERVICES

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I. INTRODUCTION

There are several operational activities unique to a "dry" spent fuel cask. During loading, it is necessary to rapidly displace water and dry out the fuel cavity. During unloading, it is necessary to "cooldown" the hot fuel and cask internals prior to placing the cask in a spent fuel pool. Techniques for rapidly and efficiently performing dryout and cooldown were developed for the NLI 1/2 Legal Weight Truck (LWT) cask at the Barnwell Nuclear Fuel Plant (BNFP). The results of this testing are reported. The techniques developed can be utilized equally well for larger dry casks such as the NLI 10/24 rail cask. The test results indicated that these dry cask operations should not cause problems during loading and unloading in excess of that experienced with a wet cask. In fact, elimination of coolant sampling and the need to meet coolant activity limits is a distinct advantage.

II. DRYOUT

The Certificate of Compliance (COC) for dry casks typically states that water will be removed and the cask cavity be dry prior to shipment. The problem is how to assure that the cask is truly dry after the closure head is bolted shut. It was necessary to develop a technique that was not only safe and rapid but that also gave indisputable evidence of the "dryness" of the cavity. The technique developed involved a high vacuum vaporization of residual water after air pressure displacement of the bulk of the water from the cavity. This vacuum drying technique does not rely on heat from the nuclear fuel and is operable even when the cask body is cold (less than 50-60°F). It can be performed in parallel with other loading operations such as decontamination. Typically, it requires only 15-30 minutes to perform. Evacuation of the cask cavity is also a necessary step prior to filling with helium. Additionally, attainment of cavity pressures in the 1 - 3 torr* range is an excellent check of the leak tightness of the closure seal.

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* 1 torr = 1 mm Hg pressure

There are several key ingredients to assuring successful dryout:

(1) Prior Removal of Bulk of Water in Cask

It is impossible to boil off a layer of water more than one inch deep in a reasonable period of time. This is particularly true in a cask with a cold body and aged fuel. Only a small amount of the residual water will be "flashed" when the vacuum is first drawn. The drying operation is dependent upon the rate of heat transfer between the cask floor and residual water temperatures. The thermal driving force is increased by lowering the vapor pressure (and hence saturation temperature) of the boiling water. This temperature can be so low that at times, frost has been observed (through a transparent plexiglass head used in an empty cask during test development). A highly efficient drain tube was developed to assure that only a small quantity of water remained. The tube was shaped to draw out all but a thin residual water layer (less than 1/4" deep). The tube shape minimizes swirls and vortices in the vicinity of its entrance.

(2) Properly Sized Vacuum Pump

The specific volume of steam vapor at 5-10 torr is 75-150 times that of steam at atmospheric pressure. The vacuum pump must have sufficient capacity to remove a large volume of steam even though the mass of water is relatively small. A Stokes, Model 148-H 50 CFM industrial vacuum pump performed ideally. For vacuum drying of a rail cask (cavity volume approximately 70 ft^3 versus 7-1/2 ft^3 for the NL 1/2) a 150 CFM pump would probably be used. These pumps employ a "ballast" valve which permits steam vapor to escape directly through the pump seal oil. It is advisable to allow the pump to operate in no-load condition for about 30 minutes prior to evacuating the cask thereby heating the seal oil. This prevents vapor from condensing in the pump.

(3) Sensitive Vacuum Gauge

Total dryout of the cask is assured when the cavity vacuum drops below about 1-2 torr (saturated vapor temperature less than 35°F). Indication of this low vacuum was observed with a "Pirani" type gauge. Figure 1 presents characteristic dryout curves for three different situations. Curve A illustrates proper operation. Curve B occurs when the vacuum pump is slightly undersized or a thin layer of water remains in the cask. Curve C (no dryout) occurs either when the cask closure is leaking; the pump oil is badly contaminated with water; or a deep layer of water still remains in the cask.

III. COOLDOWN

The temperature of the fuel in a dry cask at design heat load may be 200-400°F higher than a wet cask. This does not cause any shipping safety problem; however, it does require that the fuel pin and basket temperatures be lowered below the boiling point prior to unloading the cask in a spent fuel pool. A cooldown system was designed for the BNFP fuel receiving station(1) (see Figure 2). Operation is based on the initial slow gravity flow of hot pressurized water into the cask. This is followed by depressurization of the coolant and then rapid circulation of cool water through the cask. The coolant flow is recycled in this closed system. The system also has provision for filtering and demineralization of the coolant.

For illustrative purposes, the cask system can be divided into three discrete heterogeneous regions at design heat load: (1) nuclear fuel at 700-800°F; (2) fuel basket at 400°F; and (3) cask body at 250°F. The system operation is in three steps:

Step One - Fuel Cooled - Hot pressurized water at 400°F (~235 psig) is admitted to the cask (the water temperature is approximately equal to the average basket temperature). The coolant is vaporized

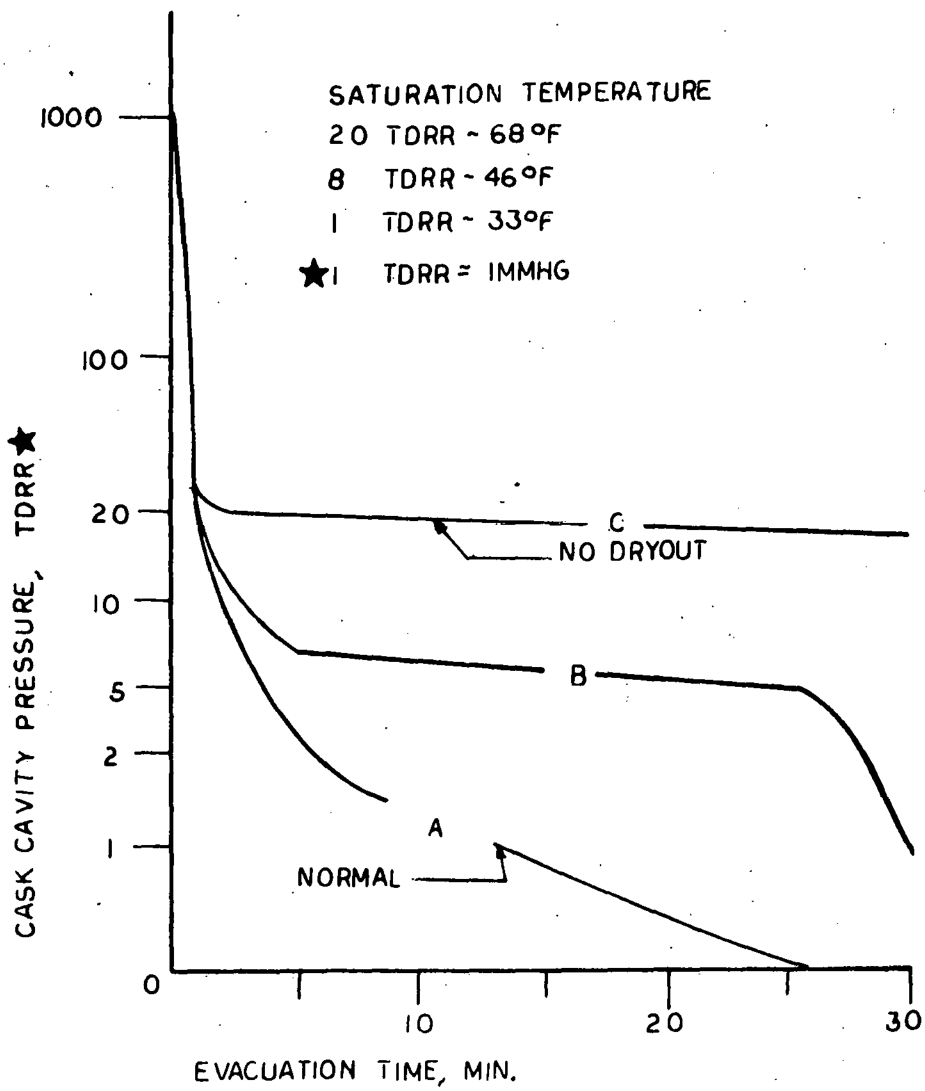


FIG. 1 – CHARACTERISTIC CASK DRYOUT CURVE

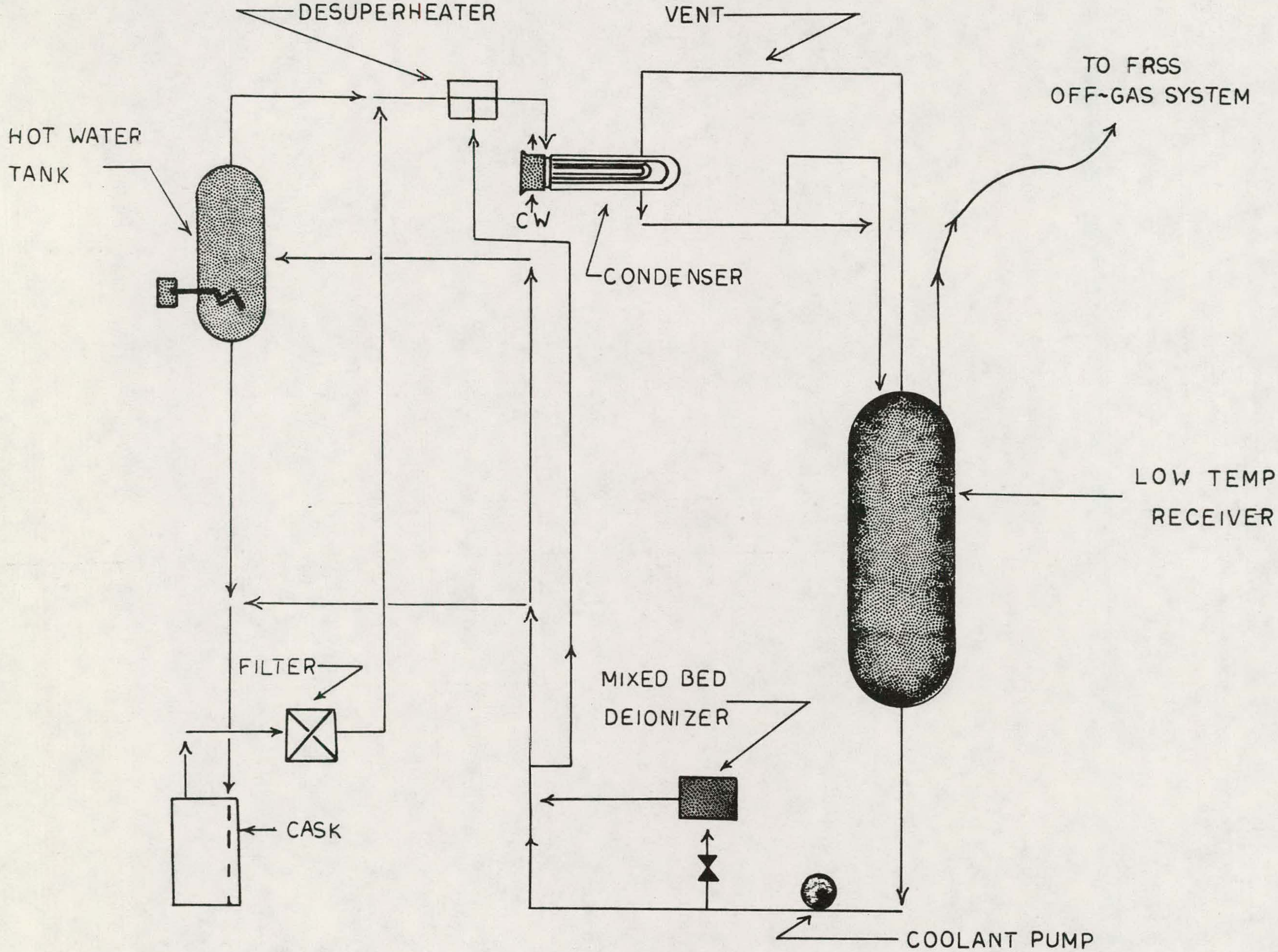


FIG. 2-BNFP COOLDOWN SYSTEM PROCESS FLOW DIAGRAM

when it contacts the hot fuel. The steam vapor is piped to a heat exchanger and condensed. The condensate is returned to the hot water heater and recycled. Gravity flow of water is continued until the cask is full. At the conclusion of this step the fuel will have been cooled to the basket temperature.

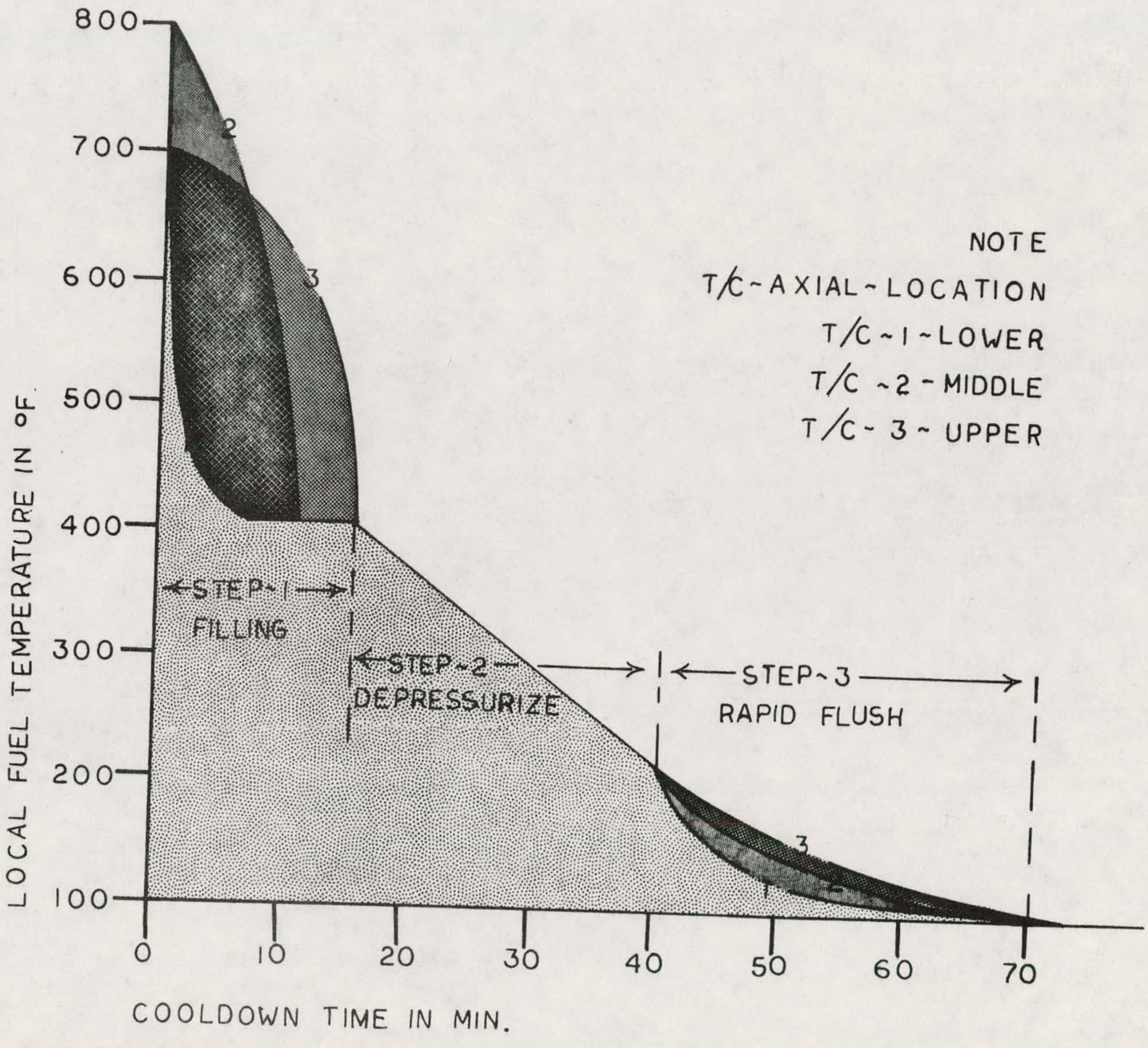
Step Two - Coolant Depressurized - The cavity is vented to atmospheric pressure and depressurized. The temperature of the water, fuel, and the basket gradually drops to about 212°F.

Step Three - Rapid Flush - Water at room temperature is rapidly flushed through the cask until the fuel, basket, and cask inner wall temperature is lowered to 150°F or less.

The testing was performed using the NLI 1/2 cask and the heated PWR mockup fuel assembly fabricated by Wachter Associates.(2) The tests were run with fuel heat levels ranging from 20% to 100% of design. The operating procedure established matches the inlet water temperature with the average basket temperature in Step One. This reduces cooldown time and prevents thermal shock to the cask body. Under low fuel heat conditions, the inlet water temperature may be as low as 200°F. The tests corresponded to a wide range of fuel "aging" prior to shipping (typically, from six months to about 3-4 years). As the fuel decay heat level in the test was increased upward to the design rating (10.6 kwt), the cooldown time increased from about 20 minutes to one hour. This was due to the hotter temperature of the fuel and cask. Figure 3 illustrates the characteristic cooldown curve. Fuel temperatures derived from thermocouples mounted at three axial positions are plotted as a function of cooldown time. The AGNS cooldown system worked in a smooth and predictable fashion. No pressure transients or boiling instabilities were observed.

One potential operating problem was uncovered that affects fuel unloading after cooldown. The cask cooldown system adequately cools the fuel and the cask internals. However, the cask body is not cooled by the

FIG.3—CHARACTERISTIC COOLDOWN CURVE BNFP COOLDOWN SYSTEM — 10.6KWT (NL 1/2 DESIGN RATING)



cooldown system. This is due to the physical characteristics of the cask and is not a fault of the cooldown system. The stored heat in the mass of the cask body and neutron shield is considerable, and the rate of heat transfer from the cask body to the coolant is relatively low. The heat from the cask will preferentially flow into the cask cavity water after cooldown. If the cask body temperature is greater than about 220°F, the heat from the cask body supplemented by fuel decay heat will rapidly reheat the cavity water. Boiling will begin in 1.5 hours. Continued rapid flushing of the cask during cooldown (Step 3) for an additional 30 minutes to one hour will not change this, due to the low heat transfer rate. Fortunately, the time needed to place the cask into the pool after cooldown is about 20-30 minutes. This problem has been circumvented with the NLI rail cask. An auxiliary water cooling system mounted on the rail car maintains the cask body temperature below 150°F during shipping.

IV. PORTABLE COOLDOWN SYSTEM

There is a need for a portable cooldown system. This system would be used for cask unloading during emergency conditions or at locations where a permanent system is not available and rapid cooldown is not required. Figure 4 is a photograph of the cooling skid which was developed. The system design differed from the BNFP cooldown system in the following ways:

(1) Feedwater was admitted at a slow rate at room temperature and heated by the cask and fuel (versus preheating with a hot water heater).

(2) Coolant flow was not recycled but directly discharged to the spent fuel pool.

(3) Steam vapor developed in the cask was condensed in the tubeside of a heat exchanger suspended in the fuel pool. The fuel pool water serves as the heat sink.

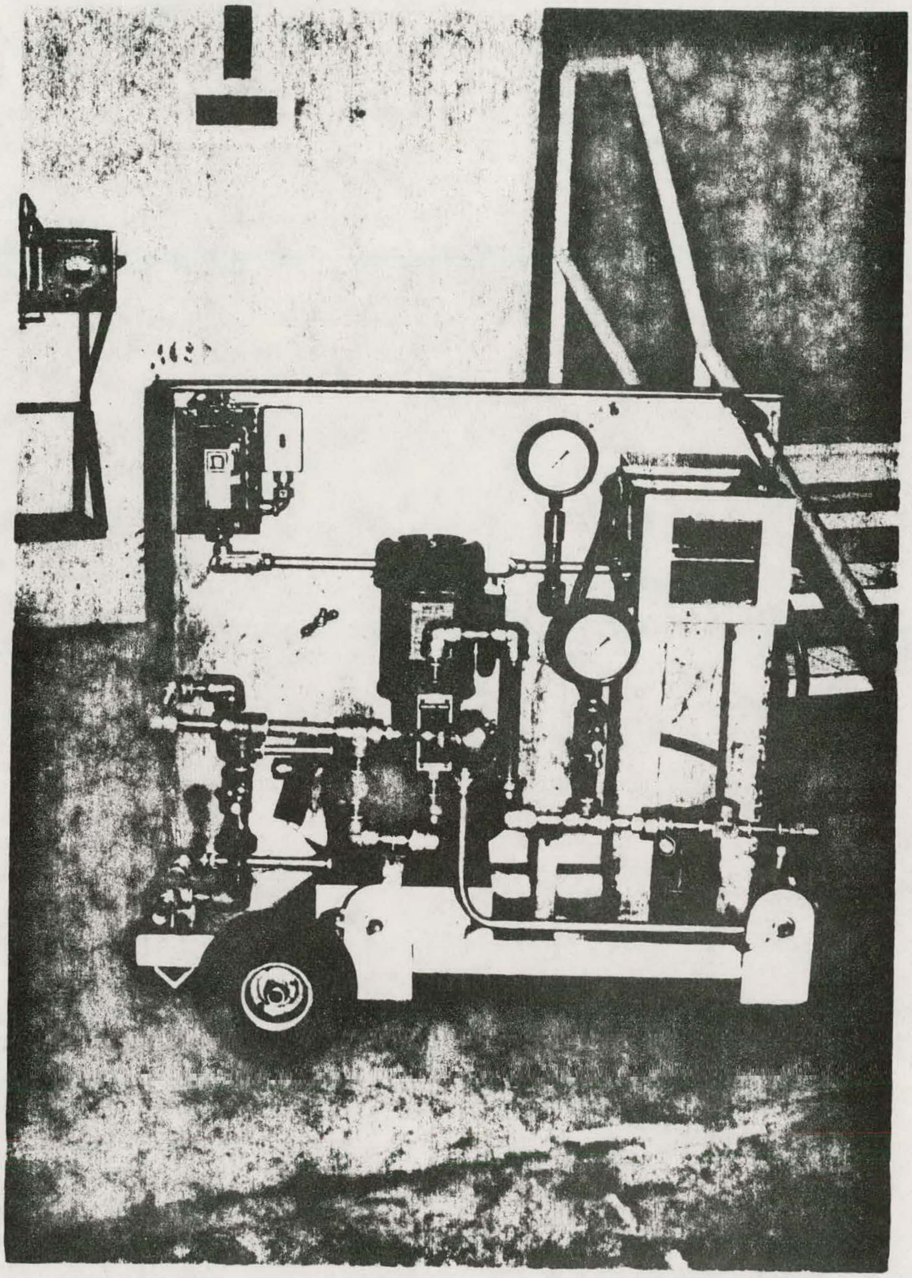


FIGURE 4 - PORTABLE COOLDOWN SYSTEM SKID

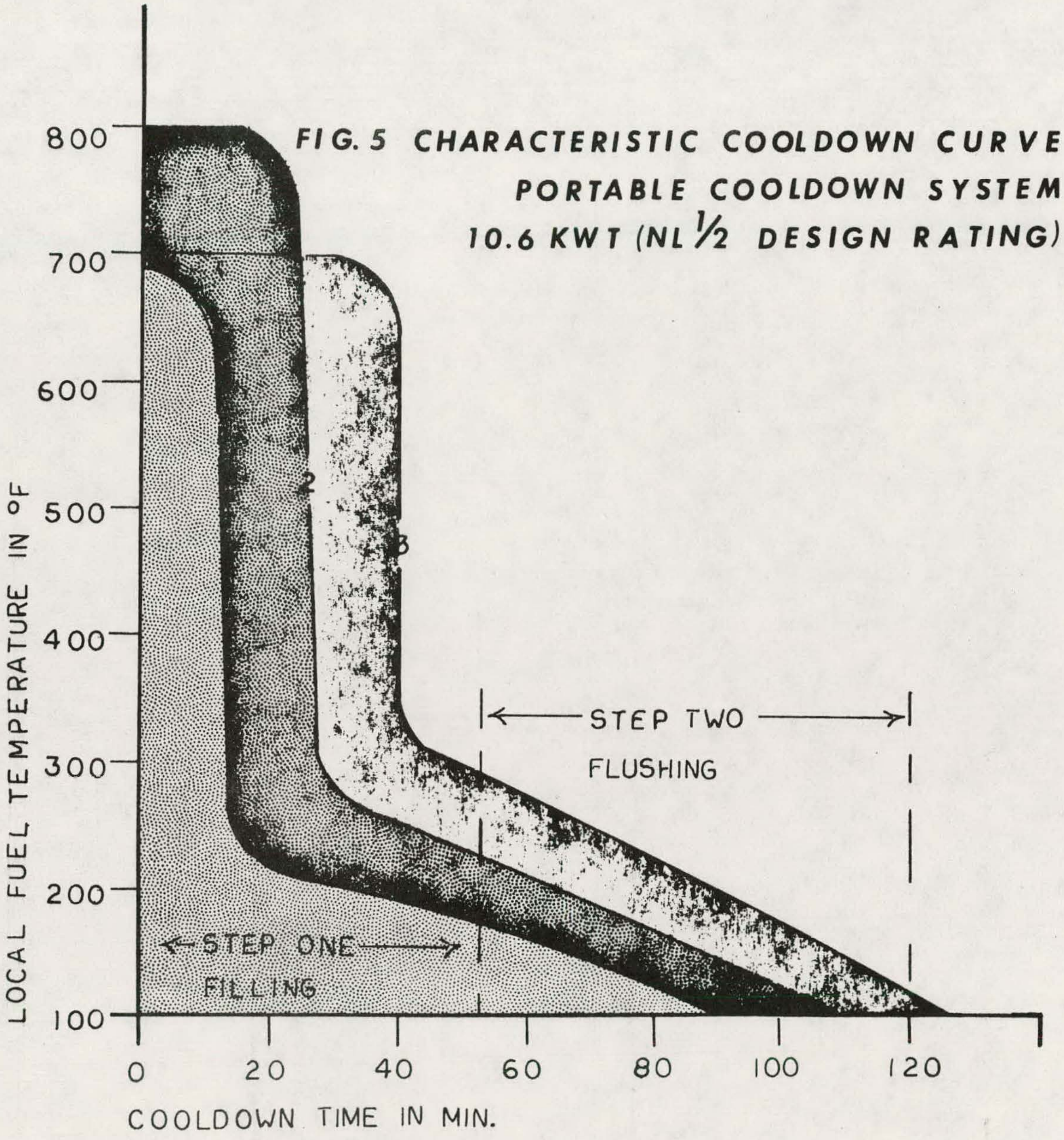


FIG. 5 CHARACTERISTIC COOLDOWN CURVE
PORTABLE COOLDOWN SYSTEM
10.6 KWT (NL ½ DESIGN RATING)
800
700
600
500
400
300
200
100
LOCAL FUEL TEMPERATURE IN °F
2
3
STEP TWO
FLUSHING
STEP ONE
FILLING
0
20
40
60
80
100
120
COOLDOWN TIME IN MIN.

(4) System pressure was maintained manually by throttling steam issuing from the cask.

The system was tested at three heat levels from 30% to 100% of design thermal rating. Cooldown took from one to two hours. Cooldown was continuous, and no erratic pressure or thermal transients were observed. Subsequent evaluation of the test results did not reveal any areas of high thermal stress to the cask body, cask internals, or the fuel. Figure 5 illustrates the characteristic cooling curve for this system. There are two distinct cooling steps:

(1) Filling the cask with water and cooling the fuel to about 240°F

(2) Slow flushing of the cask internals with cool water until the fuel and basket reaches 150°F or less.

Shipments of "well-aged" fuel are sufficiently cooled to allow regular use of a portable cooldown system. For truck casks, this system should be equally as safe and rapid as the permanent system employed at the BNFP. Cooldown of fuel which has aged for 3-4 years prior to shipping involves little more than filling the cask cavity with cool water.

References

1. Hager, E. R., A Design for a Cask Cooldown System, Proceedings of the Fourth International Symposium for Packaging and Transportation of Radioactive Material - 1974, page 702.

2. Anderson, R. T., Thermal Testing a Dry Spent Fuel Cask, Presented at the Fifth International Symposium for Packaging and Transportation of Radioactive Material - May 1978.