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TREATMENT OF WATER IN NUCLEAR FUEL STORAGE BASINS TO CONTROL RADIOACTIVITY RELEASE

Edwin C. Bertsche

E. I. du Pont de Nemours and Company
Savannah River Plant
Aiken, South Carolina 29801

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CONTENTS

Abstract

Visibility and radioactivity control in the fuel component storage and disassembly basins at the Savannah River Plant are maintained with a newly developed purification system. Visibility required to conduct operations beneath 30 ft of water is obtained by using sand filters at high flow conditions. Nonvolatile radioactivity is reduced to low values by deionizer resins operated beyond conductivity breakthrough into the range of radioactivity breakthrough. Settled sludge from sand filter back-washing and contaminated regenerating solutions from the deionizers are stored in underground tanks. Radioactivity releases are less than 1% of the limits proposed by the Federal Radiation Council.[1]

Experimental work was performed to develop the application of sand filters to operate at high flow rates with an effluent turbidity below 0.1 JTU.[2] *Filtration efficiency of SRP sand filters is dependent on the characteristics of the solids in the feed water and the degree to which filterability can be improved by addition of coagulant aids. It is independent of flow up to flow rates of 15 gpm/ft^2 (higher flow rates have not been tested). Effluent turbidity remains below 0.1 JTU with no indication of breakthrough. Total water throughput is dependent on the amount of solids removed and is independent of flow rate and concentration of solids.*

Background

The Savannah River Plant of the Atomic Energy Commission (operated by E. I. du Pont de Nemours & Co.) has nuclear reactors that use heavy water (D_2O) as moderator and coolant. Irradiated fuel components discharged from the reactor carry removable radioactivity both dissolved in residual heavy water clinging to the components and adsorbed in the oxide film covering component surfaces. These components are stored underwater in the storage basin for cooling and radiation shielding. After short-lived isotope and fission product radioactivity decay sufficiently, the fuel is shipped to the separation areas.

Good water clarity is required to control storage, disassembly, and loading operations conducted under 30 ft of water. However, untreated water becomes turbid because of the growth of algae and bacteria, corrosion of mild steel equipment, and spalling of oxide film from component surfaces. Algae and bacteria growths have been eliminated by excluding food materials from the basins (especially phosphate-containing detergents) and by using soft soap for floor cleaning and cask decontamination.

Water in the fuel storage basin contains both radioactivity and turbidity. Radioactivity in the heavy water clinging to the components disperses in the basin water within minutes; however, most of the radioactivity in the oxide surface film diffuses in about a week. The storage basin is always isolated from the disassembly basin until the fuel has aged sufficiently and all significant radioactivity has been removed from the water. In the past, radioactivity was removed from the storage basin water by recirculation through a portable diatomaceous earth filter followed by a portable mixed bed deionizer. The deionizers and filters operated without unusual problems. These portable units were cleaned and regenerated in separate facilities and radioactive wastes were stored in monitored underground waste storage tanks (figure 2).

Program for Minimizing Radioactivity Releases

A three-part program was developed to decrease the amount of radioactivity released to plant effluent streams:

1. Minimizing tritium entering the storage basin.
2. Improving the soluble radioactivity removal process.
3. Maintaining water clarity and minimizing release of particulate radioactivity.

Minimizing Tritium Entering the Storage Basin (Figure 3)

A fuel component being discharged from the reactor contains tritium (DTO) in the heavy water (D_2O) clinging to the fuel and as hydrates in the surface film. Previous tests had demonstrated that both forms of tritium could be removed almost completely by flushing the fuel surface with light water for a short time (10 to 20 seconds). The discharge machine is equipped with water cooling facilities to prevent an irradiated component from overheating if the machine becomes temporarily inoperative. This cooling facility was modified to flush light water (H_2O) over the inner surfaces of the irradiated components during transportation to the storage basin, and component design was modified to improve distribution of the flush water. The effluent flush water contains about 60% of the tritium (DTO) on the fuel component; further component modifications are being made to increase the efficiency of tritium removal. Effluent flush water is collected, purified, and reconcentrated for reuse in the reactor system.

Radioactivity Removal (Figure 4)

The nonvolatile radioactivity which is not flushed out of the D_2O film and that which diffuses from the oxide surface on the irradiated component during storage collects in the storage basin at a higher concentration than in the disassembly basin. Therefore, during discharge, the storage basin is isolated to prevent radioactivity from migrating to the disassembly basin. First, the soluble nonvolatile radioactivity is removed from the storage basin; then slowly diffusing soluble radioactivity is removed from the storage and disassembly basins.[3]

The deionizer recirculation system was installed to cope with large releases of radioactivity into the basin. At the start of each discharge, water is recirculated through a deionizer from the surface of the storage basin where the components are deposited in the basin and where water turbidity is at a minimum (to decrease deionizer pressure drop buildup). Because mixed bed deionizers have a rapid, hard-to-detect breakthrough for mobile ions, such as radioactive cesium, and will not remove submicron particulate activity, all deionizer effluent is recirculated to the storage basin in order to prevent the release of radioactivity.

The deionizers utilize only about 50% of their radioactivity removal capacity when ionic breakthrough occurs (figure 5). Storage basin water is then further recirculated through the deionizer until deionizer effluent activity reaches 75% of the influent radioactivity. After regeneration[4], the deionizer is returned to service for further soluble radioactivity removal until the total soluble nonvolatile radioactivity in the storage basin is reduced to an acceptable level. At this time filtered water is added to the storage basin and the corresponding deionizer flow is directed to the plant effluent until the tritium concentration in the storage basin is below the maximum permissible value for personnel exposure.

At this time, the gates between the storage and disassembly basins are opened and the deionizer effluent is recirculated through the transfer pits to the disassembly basin and back into the storage basin until the maximum nonvolatile radioactivity in all basins is below a specified value. This maintains an acceptable level of radioactivity in the transfer pits where shipping casks are loaded underwater, and facilitates decontamination of cask surfaces.

Maintaining Water Clarity

Fuel transfer and disassembly operations require excellent visibility through the 30-foot depth of water in the basin. However, turbidity formation causes water clarity to deteriorate in 24 to 48 hours. The original method of purging the basin with filtered water released this turbidity and the adsorbed radioactivity to the effluent. This release can be prevented by making the disassembly basin a closed system, by stopping the filtered water purge, and by providing an efficient method for preventing turbidity formation or for removing turbidity. Analyses of suspended solids from the basin by optical and electron microscope methods and radioautography showed that the particles ranged from about 0.01 to 4 microns in diameter while chemical and spectroscopic analysis showed that the particles contained over 80% iron oxides, about 15% aluminum oxides, and about 5% miscellaneous material.

CORROSION INHIBITION

These analyses indicated that turbidity was caused by corrosion and might be prevented by the use of corrosion inhibitors effective against mild steel, aluminum, and stainless steel (type 304) corrosion. These inhibitors cannot interfere with visibility, promote growth of organisms that would themselves cause turbidity, nor contain chemical elements which can be activated into undesirable isotopes if small amounts enter the reactor on components recharged from the storage basin. Potential inhibitors (sodium silicate, lithium silicate, plain and synergized dichromates and phospates) were tested in the laboratory using basin water having a pH range of 5.3 to 8.0 with corrosion coupons and "Corrosometer" probes (using 4-mil wall thickness, type 1020 carbon steel). Sodium dichromate (200 ppm) gave the most favorable results in the laboratory (0.4 mil per year [mpy]) and was therefore tested in an isolated section of the basin. The corrosion rate judged by the corrosion probes was limited to 0.6 mpy and the carbon steel and aluminum corrosion coupons remained clean. However, some corrosion of aluminum occurred on the stainless-steel-to-aluminum couple coupons. Visibility in the basin was not significantly impaired by the dichromate solution; objects at the bottom were clearly defined but appeared the typical yellowish-green chromate color.[5]

Possible chromate activation in the reactor led to a second test in a larger recirculated section of the basin using literature recommendations of 30 ppm of sodium silicate at a pH of 7.0. Although the silicate appeared to reduce corrosion, release of air from basin water prevented reliable measurement of basin visibility. Corrosion inhibitor tests were discontinued and will be resumed later if improvement in sand filter quality or capacity is desired.

SOLIDS REMOVAL – PRELIMINARY TESTS ON SAND FILTERS

At the start of this program, no satisfactory method of maintaining water clarity had been demonstrated. A survey was made of methods of removing iron oxide and aluminum oxide turbidity, including use of diatomaceous earth, cartridge, and sand filters; centrifuging; and air flotation. The indicated particle size range (0.01 to 4 microns) would normally dictate the choice of diatomaceous earth filters. However, sand filters were chosen for preliminary evaluation because diatomaceous earth filters in this system had previously given difficulty with rapid increases in pressure drop, low throughput per run, and limited flow rate per unit area, and also because cartridge filters had proved ineffective. Centrifuging was not studied because of potential maintenance and radiation problems, and insufficient knowledge was available about air flotation (especially about the specific chemicals required for efficient removal of iron oxide and the effect of this process on turbidity).

Sand filters using air scour to clean the sand prior to backwash and stored backwash water appeared to be ideal for our system. The air scour technique promised efficient cleaning with no moving parts and low maintanance costs. The mixed sand and anthracite filter media and use of chemical coagulation additives promised high solids holdup capacity and flow rates substantially higher than the 2 to 3 gpm/ft^2 standard in municipal water treatment.[6]

Laboratory tests on basin water (at 2.5 gpm/ft^2 with 6 in. of anthracite [0.76 mm][7] and 14 in. of sand [0.45 mm] in 1 in. ID glass columns) demonstrated that water samples containing high turbidity (1 to 6 JTU) could be filtered continuously (without use of coagulation additives) to an effluent turbidity below 0.10 JTU. However, samples containing low turbidity (1.0 ppm) required the addition of small amounts (0.2 ppm) of cationic coagulation additive (such as Nalco 600, Calgon 225, Polyhall M-603, or Purifloc C-32) to maintain the effluent turbidity below 0.10 JTU. (Nonionic and anionic coagulant aids were much less effective.) Frequently the floc concentrated at the top of the anthracite and had to be broken up manually before backwashing at 15 gpm/ft^2 would clean the filter media. Attempts to clean the sand with an air scour were ineffective because wall effects caused the sand to bridge and drove the water out of the sand. The sludge in the backwash slurry settled rapidly (5 to 10 minutes), leaving a relatively clear supernate and about 5% by volume of solids.

A 4-filter test unit (figure 6) was constructed using 5½ in. ID clear plastic tube, filter media of 6 in. of anthracite [0.77 mm] and 18 in. of sand [0.49 mm], and a 3 in. gravel layer to provide air distribution. This unit was installed in the plant to evaluate actual operating conditions (fresh basin feed water, flow rate, air scouring and backwash techniques, coagulation agents, effluent turbidity, rate of pressure drop increase, and throughput). Again, wall effects caused the air to drive the water out of the sand, and prevented air scouring or water backwashing alone from cleaning the sand. Vigorous air scouring and effective cleaning of the filter media were obtained by mixing water with the upflow air; this permitted the sludge to be removed readily from the filter media by backwashing. Filtration was excellent; the majority of the solids collected in the top 2 in. of the anthracite layer and a smaller amount at the top of the sand layer. The filter reduced the turbidity in the feed water

(0.56 JTU) to an average effluent turbidity averaging of 0.03 JTU (max 0.10 JTU) over a 12-day period at feed rates of 2.5, 5.0, 7.5, or 10.0 gpm as long as 0.2 ppm of cation coagulant aid was added to the feed.

A semiworks unit (figure 7) was then constructed to evaluate the final plant process, to obtain design information, and to reduce final plant costs. This setup used a standard commercial 4 ft diameter filter loaded with 18 in. of anthracite [0.71 mm] and 18 in. of sand [0.42 mm] with its own air scour, backwash settling, and supernate recycling systems; it was operated in a recirculation system on a small isolated basin. Test results confirmed previous work and demonstrated that the filter operated effectively at feed rates between 4.0 and 9.4 gpm/ft^2 on continuously recirculated feed water, provided that 0.2 ppm cationic coagulant aid was added to the feed. The effluent turbidity was consistently below 0.1 ppm, and the basin water turbidity decreased during the test from 2.0 JTU to 0.38 JTU – a level which permitted excellent visibility through the water in the basin. The air scour and backwash operations after each run were effective in reducing the pressure drop through the filter to the initial value and in preventing the buildup of radioactivity in the filter. No difficulty was experienced in getting the backwash solids to settle nor in recycling the backwash supernate to the filter.

Commercial water filters are normally designed to operate at 2 to 3 gpm/ft^2. However, theory indicates that for any particular, constant type of solids, the rate at which the pressure drop increases should be dependent only on the amount of solids collected and should be independent of flow rate after it is corrected for the flow characteristics of the filter (i.e., for pressure drop deviations from a constant flow rate). The preliminary test results indicated that the rate of increase in pressure drop at flow rates between 2.5 and 9.4 gpm/ft^2 was constant at 18 ± 3.6 ft H_2O/ft^2/lb of solids filtered (when corrected to a standard flow rate of 5 gpm/ft^2). Thus the plant filters designed for flow rates of 5 to 15 gpm/ft^2 would permit filter runs to 1 to 2 weeks before the maximum operating pressure drop was reached. Actually, filter runs are limited to 48 hours to maintain low radioactivity levels in the vicinity of the unshielded filters.

PLANT FILTER INSTALLATION

The plant filter installation (figure 8) was designed to maintain clarity using recirculation and filtration of a closed basin, rather than by purging. The basic flow diagram for the system is shown in figure 9. Each air scour filter contains 100 ft^2 of filtering area (the filter media consists of 18 in. of anthracite [0.72 mm] over 18 in. of sand [0.36 mm]) and is operated at 5 to 7 gpm/ft^2. The storage basin and the disassembly basin were provided with separate 1000 gpm pumps feeding the parallel filters through a common header with the filtrate lines arranged to permit the effluent to be returned to either basin. The filters have maintained a filter effluent turbidity[8] below 0.1 JTU and a basin turbidity below 0.3 JTU, thus providing excellent visibility for manipulations and observations through 30 ft of water.

A vertical traverse showed that turbidity particles settle under the influence of gravity. The pump suction lines are therefore located 30 ft below the surface of the water and directly underneath the major sources of turbidity generation to feed the filters with the highest concentration of solids. The filter suction lines are provided with suction breaks 18 in. below the normal water level to prevent the water level from going below the depth required for shielding the fuel. The filtered water is returned just below the surface of the water at locations remote from turbidity generation to sweep the turbidity toward the pump suction lines. A chemical feed system adds the desired amount of cation coagulant aid to the feed (0.2 ppm). The filters are provided with automatic and manual backwash controls which initiate a backwash cycle (figure 10) consisting of

- closing off the filter backwash storage compartment.
- draining excess water from the top of the filter bed – 5 minutes.
- air scouring the filter media – 10 minutes (figures 11, 12, and 13).

  (increased from the 5 minutes recommended by the manufacturer to improve the efficiency of radioactivity removal from the sand filter).
- settling the bed – 5 minutes (figure 14).
- backwashing the filter at 15 gpm/ft^2 for 5 minutes.
- returning the filter to operation.

The backwash is collected in an uncovered 22 ft diameter cone-bottomed vessel where the sludge settles for 2 to 4 hours before the supernate is automatically pumped back to the filter. Special precautions have been taken to prevent the backwash from entraining air into the settler because the resultant air bubbles would break through the water surface in the settler and spread smearable radioactivity on the surrounding ground. The sludge is periodically pumped from the bottom of the settler into a shielded trailer and transported to the separations area of SRP where it is drained into underground storage tanks. Sprays in the settler at the end of the pump suction line and in the trailer keep the sludge fluid during the transfer operations.

In the original installation, the filtrate flowed from the backwash storage compartment over a weir which entrained air into the open filter return line and saturated the water with air. Although de-entrainment facilities released the free entrained air, the dissolved air was gradually released in the basin when fuel decay heat warmed the water or when rotating equipment caused cavitation and bubble formation. The gas bubbles rising through the water surface contained small amounts of radioactive water which carried smearable radioactivity onto the adjacent floor and equipment. This problem was accentuated by a highly radioactive surface film (containing 50 to 1000 ppm of organic carbon) formed by particles which attached themselves to the air bubbles and rose to the surface of the water. The gas entrainment problem was solved by isolating the effluent water from the air. This was done by relocating the effluent take off point several feet below the surface of the water in the filter backwash storage compartment and by using an automatic valve to control the water level; this minimized gas evolution from the basin and eliminated the smearable radioactivity contamination problem.

Some carryover of filter media into the settler was experienced when improper operation of a flow control valve permitted backwash flow rates over 20 gpm/ft^2 or allowed water to enter the filter compartment during the air scour operation. This problem was solved by correcting the operation of the valve and by returning the filter media to the filter using the sludge recycle pump.

Results

The operation of the sand filter system in the first two areas at normal flow rates of 5 to 7.5 gpm/ft^2 and test rates up to 15 gpm/ft^2 has been highly successful and has permitted the filters for the third area to be designed for operation at 15 gpm/ft^2. This equipment has provided greatly improved control of activity during discharge, storage, disassembly, and shipping of fuel components. The sand filter and the recirculation system have enabled basin water clarity to be kept below 0.3 ppm without purging and has maintained excellent visibility through 30 ft of basin water. The fuel flushing system has permitted recovery of over 60% of the heavy water and tritium previously lost and higher recoveries are anticipated when proposed modifications in component design are completed. Recirculation of the storage basin water through the deionizers and filters removed nearly all nonvolatile radioactivity. The release of nonvolatile radioactivity is further decreased by purging the basin water through a mixed resin deionizer.

Notes

[1] Federal Radiation Council Report No. 2, September 1961, as modified by the report of March 1962.

[2] Jackson turbidity unit which is equivalent to ppm turbidity by weight down to about 0.3 ppm (figure 1).

[3] Minor amounts of radioactivity diffuse from the surface film after the fuel has been transferred to the disassembly basin.

[4] The regenerant solutions containing the radioactivity are stored in underground storage tanks.

[5] The solution which completely absorbed the 450 mμ blue light but none of the yellow [550 mμ] or red [650 mμ] light.

[6] JAWWA 52, 205, 1960; Walter R. Conley and Raymond W. Pitman, Test Program for Filter Evaluation at Hanford.

[7] All filter media measurements are given in effective particle size.

[8] Measured with an in-line turbidimeter.

RELATIONSHIP BETWEEN JACKSON TURBIDITY UNITS AND SUSPENDED SOLIDS

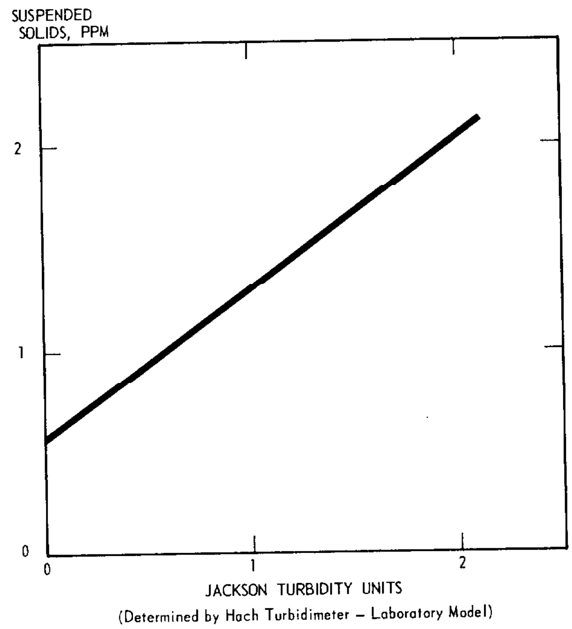


FIGURE 1

DEIONIZATION AND PURGING SYSTEM

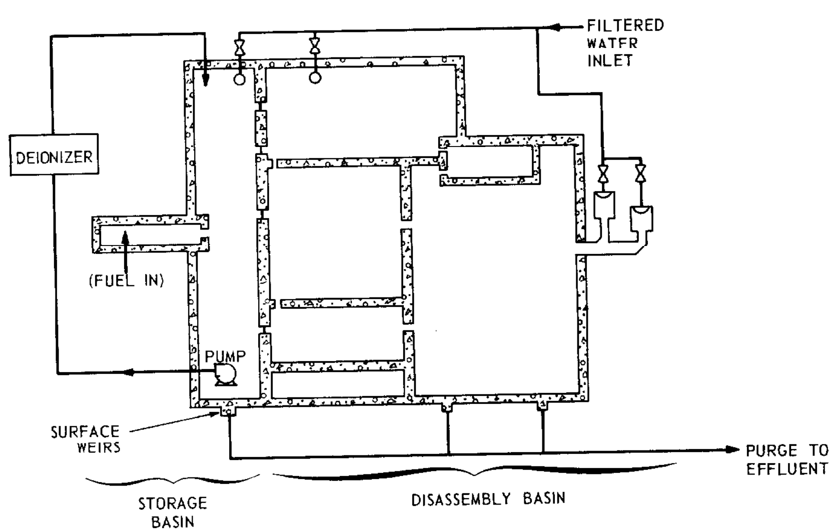


FIGURE 2

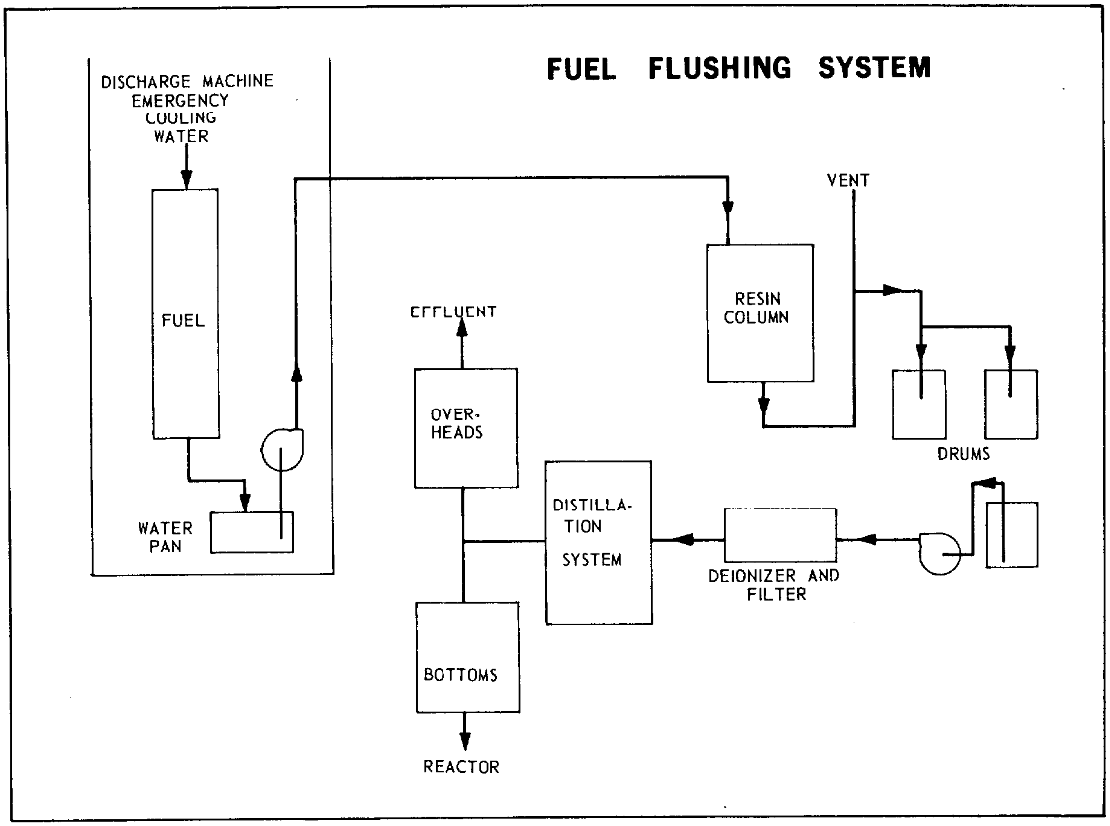


FIGURE 3

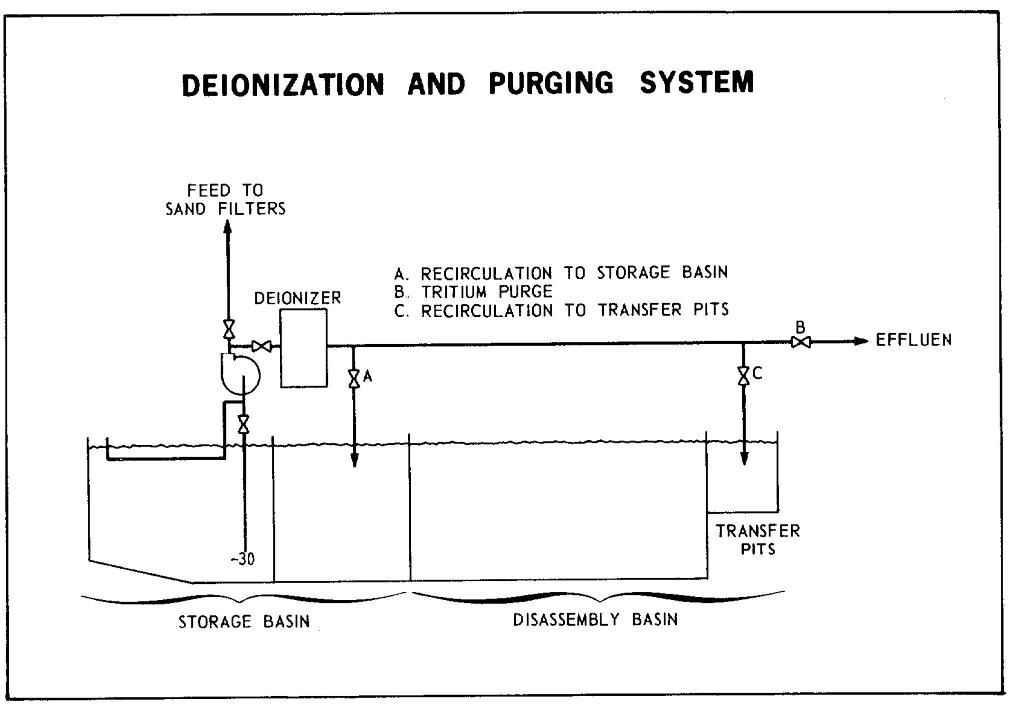


FIGURE 4

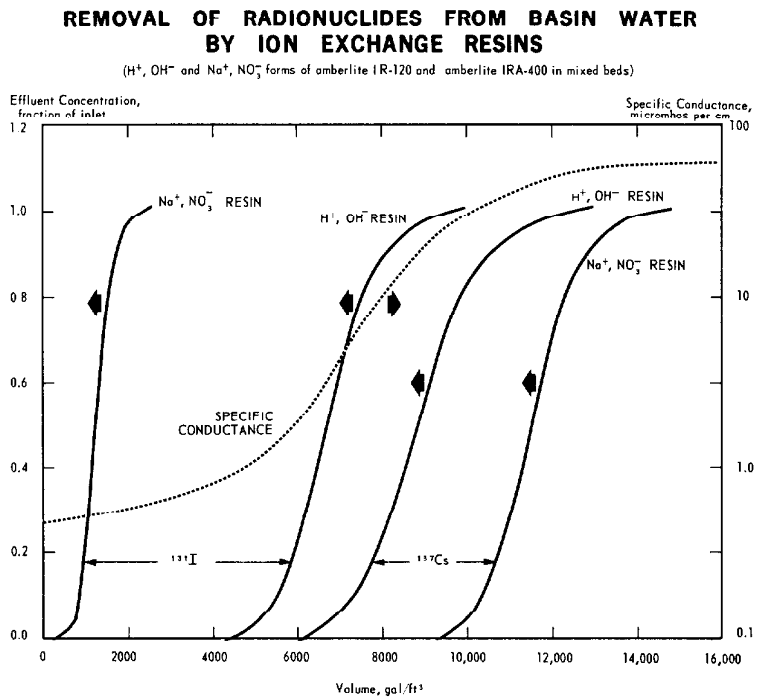
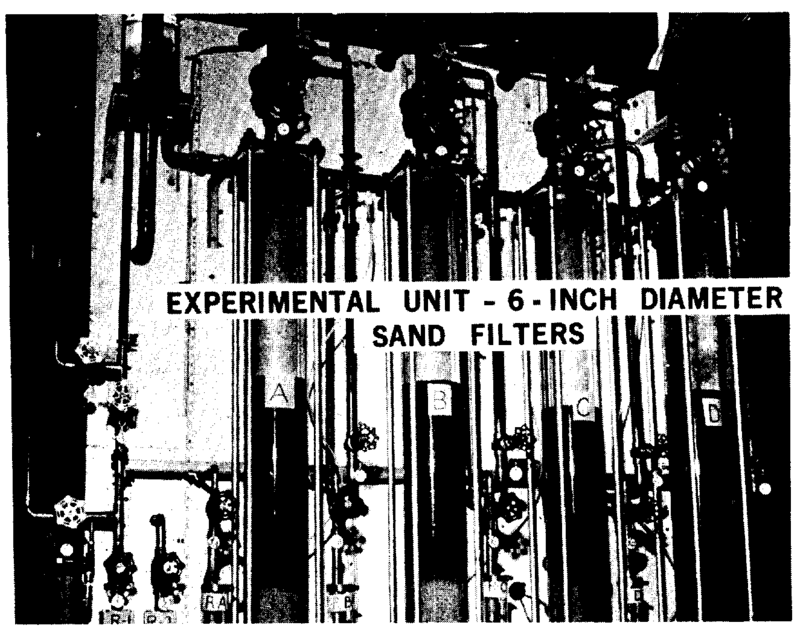
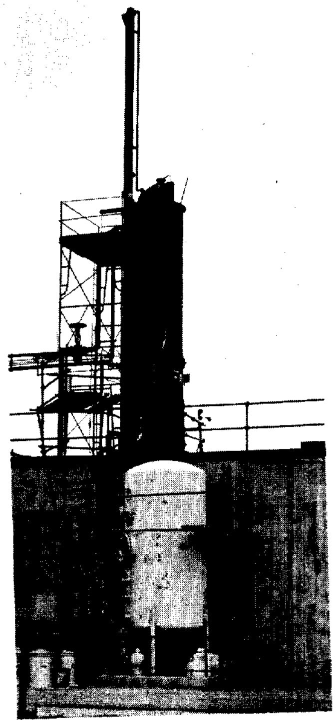


FIGURE 5



DPSPF 11668-3

FIGURE 6



PILOT PLANT SAND FILTER AND BACKWASH SLUDGE SETTLER
DPSPF 12792-6

FIGURE 7

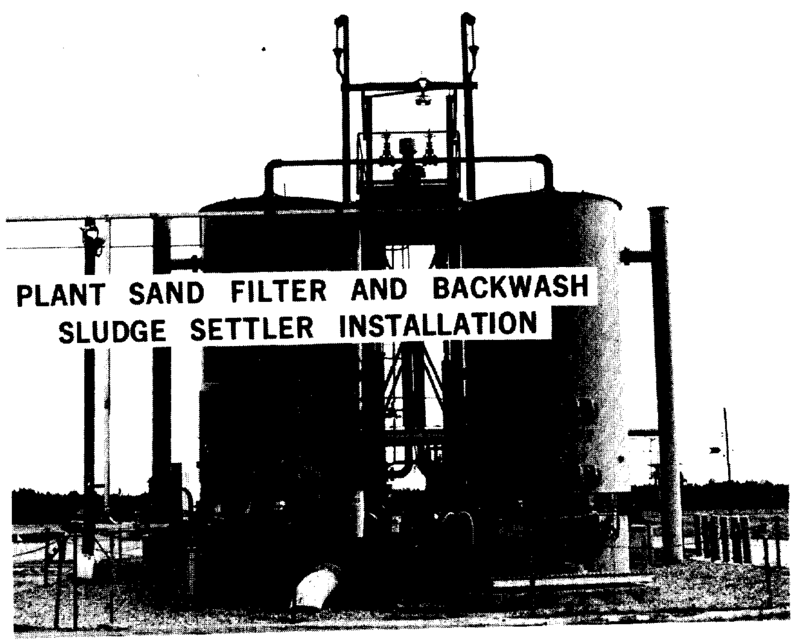


FIGURE 8 DPSPF 14663-1

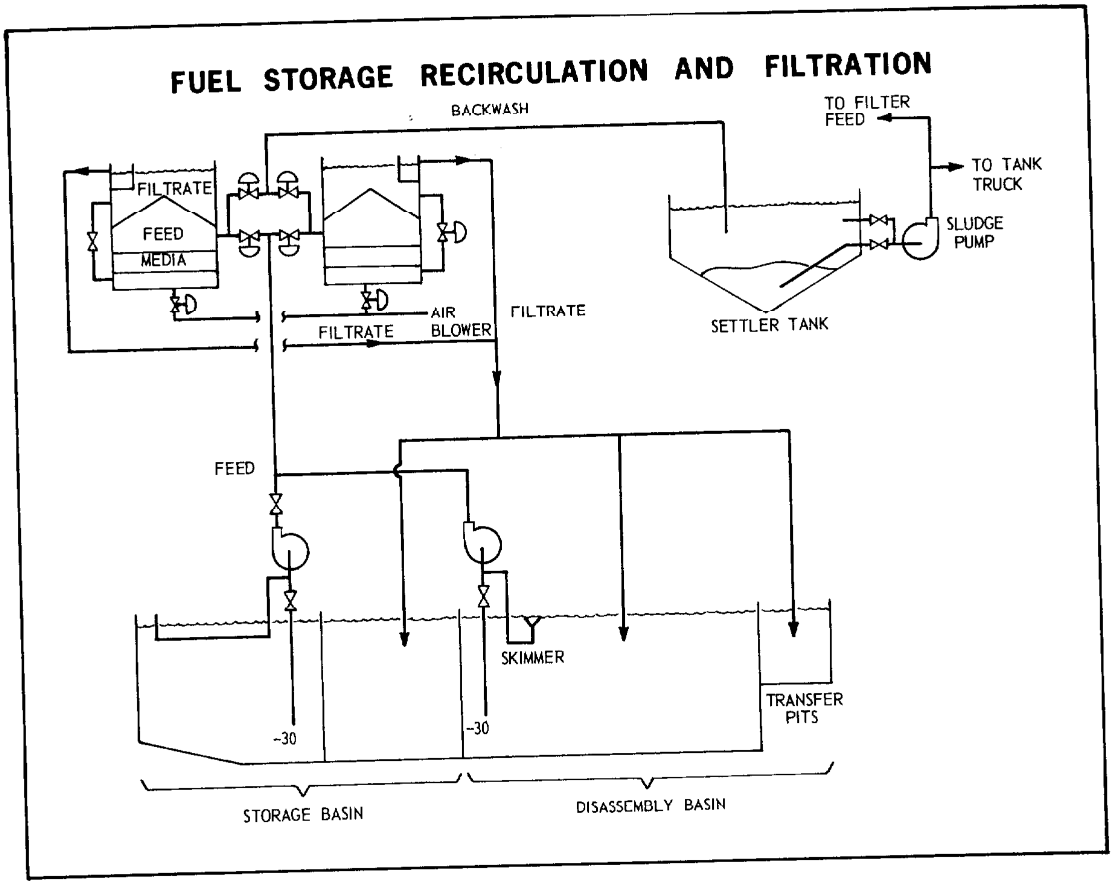


FIGURE 9

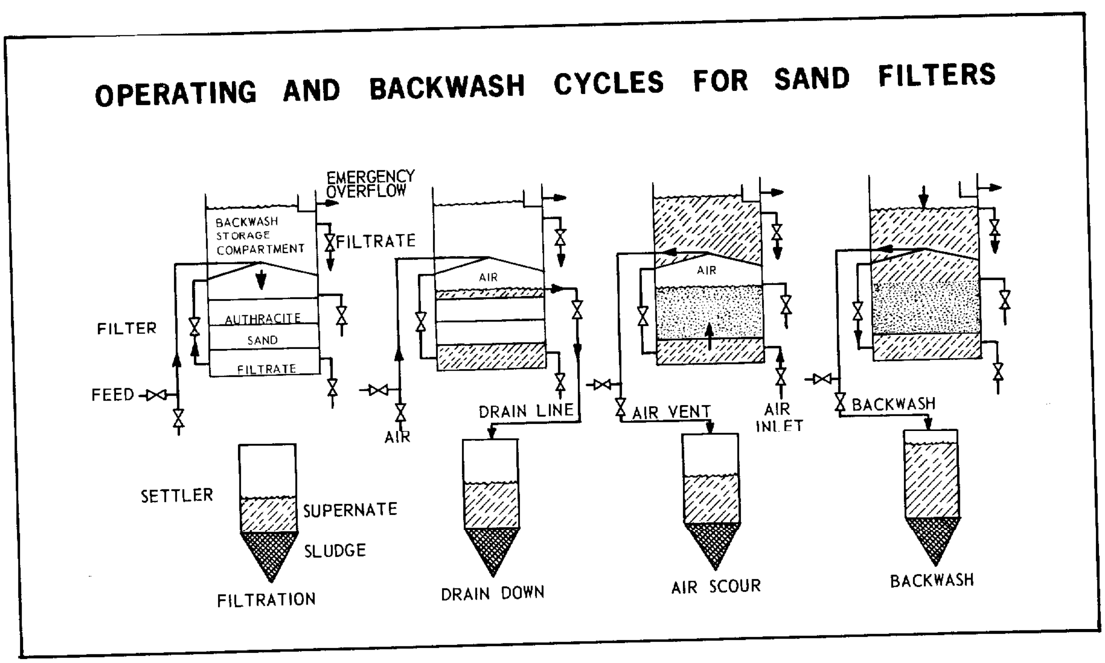


FIGURE 10

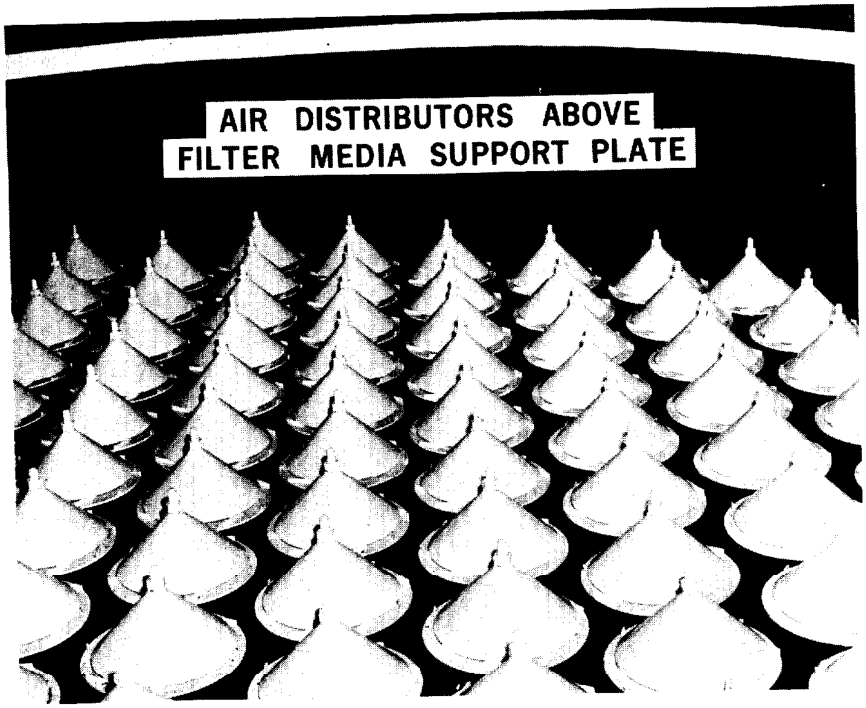


FIGURE 11 DPSPF 12991-4

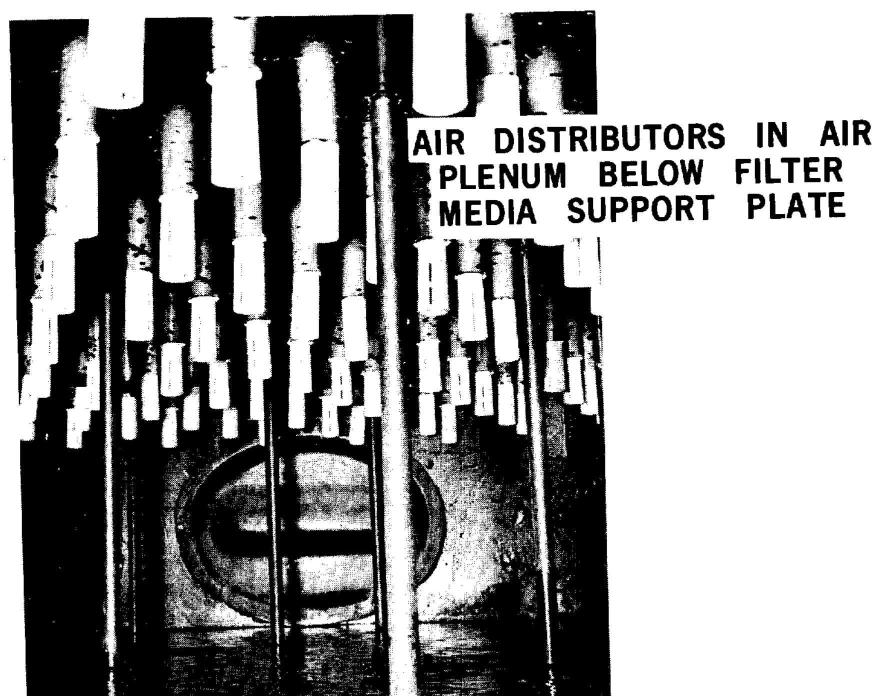


FIGURE 12 DPSPF 13019-18

FIGURE 13 DPSPF 13019-11

FIGURE 14 DPSPF 13019-14

DPSPU 71-30-12

IMPACT TESTS OF MODELS AT THE SAVANNAH RIVER PLANT

J. W. Langhaar

E. I. du Pont de Nemours and Company
Savannah River Plant
Aiken, South Carolina 29801

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J. W. Langhaar
E. I. du Pont de Nemours and Company

ABSTRACT

Impact testing of small-scale models for assessing gross deformation resistance to puncture, behavior of welds, and certain other physical attributes has been theoretically established and experimentally verified. For evaluation of the strength of bolted fastenings and leakage of closures, the validity of model testing is not so well proven but is nevertheless often considered the most reliable practical method available.

The Savannah River Plant has tested numerous models in recent years and sometimes a full-size mockup of part of a package. Results in some cases have confirmed predictions and other cases have necessitated a change in design. Several of the tests are described. The need for further study of methods of modeling closures is emphasized.

INTRODUCTION

About ten years ago the validity of model testing for assessing the behavior of shipping containers under impact conditions became a subject of serious study. In 1962, Clark and Reddi[1] showed that for a true geometric model the stresses, strains, and percentage deformation are for practical purposes independent of model size provided (a) the impact velocity is unchanged, (b) the resisting force continues to increase while the container comes to a stop, and (c) the stress-strain characteristics of the materials are not affected by how fast the stress is applied. The last of these is important because a quarter-scale model, for example, stops four times as fast as a full-scale model.

The requirements are approximately met in practice for impacts not resulting in rupture,[2] and test work has verified this even for the puncture-type accident up to the point where shearing and penetration occur.[3] A major problem is fabrication of a true model, particularly with respect to welds and fastening devices. Good correlation of results has been obtained with carefully made models as small as one-tenth scale,[2] but approximately quarter scale is more reliable and easier to fabricate. Variability of physical properties throughout a structural part such as the shell of a cask, variations in details of fabrication, orientation at impact, and other factors may significantly affect a buckling pattern, so that only the general nature and magnitude of buckling can be duplicated even with full-scale testing.

Use of models has become generally accepted as a means of demonstrating structural response to a 30-ft drop. The practice has been extended to assessment of leaktightness, although as discussed later there are some important unanswered questions in this area.

A model may be simplified by omission of features not significant for the test or by modification in some manner judged to be conservative for the test. Thus it may be a mockup of only some part of a container. Also, it may be small-scale or full-scale. Considered in this broad sense, the Savannah River Plant has during the past few years performed several 30-ft drop tests with models of different types. Results in some cases confirmed expectations but in other cases led to modification of design.

Full-size prototypes of relatively inexpensive containers have also been tested. For present purposes these are not classified as models and are not included in the discussion.

DISCUSSION

Curium Cask

This cask (Fig. 1) is essentially a tank of water 5 ft in diameter and 6 ft high, with a one-inch-thick stainless steel wall.[4] An internal birdcage structure supports the product capsules. External fins help to dissipate heat. The lid is recessed and protected from damage by a cover plate. The closure utilizes a 20-inch-diameter, spiral-wound, "Flexitallic" gasket, with seating surfaces having a finish specified as 32 rms or better. The cask is equipped with 16 fusible plugs so positioned that regardless of cask orientation at least one of these plugs will melt in the specified fire and permit escape of steam without loss of liquid water. The loaded weight is about 7 tons.

It was necessary to demonstrate that rupture of the tank would not occur and that leaktightness of the closure would be maintained after a 30-ft drop to a flat surface and after a 40-inch drop on a 6-inch-diameter penetrator. A model was fabricated to quarter scale except that standard sizes of "Flexitallic" gasket were used and the finish of the seating surfaces was about the same for the model as for the full-size cask. The loaded weight was 220 pounds.

The model was subjected to a series of 14 drops, of which only a few were considered required for demonstration of compliance and the remainder were performed for added information. Results are given in Table 1 and in Figures 2 through 8.

The puncture tests were of particular interest because experimental work at the Franklin Institute and at Oak Ridge, represented by the correlation given in "The Cask Designer's Guide,"[3] was restricted to designs with lead behind the steel plates. The degree to which the plate is stiffened by fins or edge restraint or backup material and the energy absorbed by the backup material while being pushed aside appreciably affect the thickness of steel required to avoid puncture. It was found that for a 30-ft drop onto a penetrator, puncture occurred on the bottom but not on the side or top. The fact that the top drop was off-center may have influenced the results.

Leaktightness of the model was assessed before and after tests 1, 2, 5, and 7 by pressurizing with water to 70 psig and checking for visible leaks or loss of pressure during a period of about 15 minutes. No leakage was found.

Bismuth Cask

Two casks of 24-inch inside diameter and 39-inch inside height, with solid stainless steel wall of 5-inch thickness, were constructed for shipping irradiated bismuth slugs (Fig. 9). The cavity was to contain water for effective heat removal and – because of the low melting point of bismuth – maintain a leaktight closure with no escape of coolant or other contents even under fire conditions. The casks have a design pressure of 930 psig at 525°F and are adequate for 1500 psig based on yield strength at the maximum temperature expected in the hypothetical fire. For the design contents, the calculated maximum pressure for the fire condition is about 1000 psig.

As an added safety precaution for fire conditions, a rupture disk assembly rated at 1390 psig at 525°F is provided in the cask cavity. Piping for pressure relief and for cask draining is incorporated in the lid. The lid closure uses a "Viton" O-ring; the flanged connection for piping on the underside of the lid has a "Flexitallic" gasket. The casks were hydrostatically tested at 1500 psig at room temperature with no visible leakage or loss of pressure.

Two 30-ft drop tests were performed, one with a quarter-scale model of the upper portion of the cask to evaluate the closure design and one with a full-scale mockup of the rupture disk assembly to evaluate its resistance to impact. Both tests led to design modifications.

The quarter-scale model (Fig. 10) was not pressurized or gasketed, because it was considered that relative movement of the lid with respect to the body would be a suitable measure of performance. Appreciable sidewise motion was not possible without gross failure. The maximum gap between lid and body after the drop was 4 mils, corresponding to 16 mils for the full-size cask or to only about 25% reduction in the compression of the O-ring. However, because of considerable damage to two of the six lid studs and nuts, the number was increased to twelve for the full-size casks and the nuts were recessed into the lid.

The initial design contemplated a single rupture disk rated at about 1400 psig at 525°F. For the cask upside down at impact, the head of 3 ft of water if decelerated at about 1000 G's might be expected to rupture such a disk. There was no sound basis for estimating the actual deceleration; furthermore, shock phenomena are not amenable to such simple analysis. Consequently, a mockup was fabricated as shown in Fig. 11 except that for the first test the dip tube and union-type rupture disk shown at the upper end of the tube were omitted. An available disk rated at 1322 psig at 72°F was used for the test. The vessel was filled with water except for a two-inch freeboard and pressurized with air to the maximum expected actual operating pressure of about 140 psig. The 30-ft drop caused the rupture disk to fail in what appeared to be a normal manner.

The design was changed to provide two disks in series with air in the tube between them. For the second test, the flange-type assembly contained a disk similar to that for the first test, and the union-type assembly contained a disk rated at 975 psig at 72°F. The mockup was pressurized as before, and dropped once on each end. Disassembly showed that the union-type disk had failed (as expected from the first test) but that the other disk remained intact. The modified design was therefore incorporated in the casks, except that the casks have disks of somewhat higher rating.

PM-3A Casks

The upgrading of two casks (Fig. 12) for shipping reactor cores from McMurdo Sound is described in another paper of this Symposium.[5] These casks are lead-shielded and were originally equipped with a cylindrical shroud of one-inch-thick steel for added gamma shielding during land and water transport. The shroud was not required for air transport. The shipment is dry.

Because of questionable structural integrity of the shell under hypothetical accident conditions, it was decided to extend the shroud so as to shield the entire side of the cask from radiant heat in a fire and to add similar protection for the top and bottom. The configuration of the O-ring seal was suspect with respect to lateral displacement and possible leakage under impact conditions. This O-ring was replaced by a "Gasko-seal" unit which could accommodate greater lateral movement of the lid.

A quarter-scale simplified model was fabricated to assess the integrity of the shroud, insulating plate and lid closure (Fig. 13). After a 30-ft top-corner drop (Fig. 14), the model was immersed in water, pressurized with air to 30 psig, and checked for leaks. No leakage was observed. The crash frame had protected the cask from any visible damage (Fig. 15), and measurements showed insignificant movement of the lid.

A bottom-corner drop (Fig. 16) did not cause exposure of any part of the cask body and thus did not disqualify the cask. However, there was failure of several attachment bolts of the shroud (Fig. 17). The model was repaired, reassembled, and dropped 30 ft on its side. Two sections of shroud and the bottom insulating plate came off (Fig. 18).

The model was then equipped with cables and clips to hold the shroud together, and a smaller diameter bottom insulating plate to avoid direct impact on the edge of the plate (Fig. 19). The redesign was successful in retaining the shroud (Fig. 20), but the bolts holding the insulating plate failed because the insulating plate was too stiff to conform to the bending of the bottom plate of the cask. The model was again pneumatically leak-tested, with no observable leakage.

For the full-size casks, attachment of the insulating plate was strengthened and the plate was reduced in stiffness by a factor of 5, as measured by section modulus, by making it of two steel sheets each 0.1875-inch thick separated by 0.375 inch of hardboard. It was determined by calculation that this would conform to the heavy bottom of the cask without bolt failure for impact in any orientation on a flat surface.

Both full-size casks were pneumatically leak-tested at 30 psig by immersion in one of the cask handling basins. These tests were considered necessary because of possible slight differences from the model with respect to the gasket and the contact surfaces.

Other Containers

In two recent cases, poisoned inserts of the eggcrate type were fabricated for use in existing casks. One of these was for shipment of Borax V fuel from Idaho to SRP in the bismuth casks; the other was for shipment of Spert III fuel from Idaho to SRP in the Paducah uranium-shielded demonstration cask[6] which a few years ago satisfactorily survived impact and fire tests.

In order to demonstrate structural integrity of the inserts, one-half scale models of six-inch-long sections of cask and insert were subjected to a 30-ft drop. The cask wall was simulated by a weldment of suitable stiffness resembling an I-beam rolled to a ring-shape with one flange serving as the inner cask shell and the other flange as the outer cask shell. The fuel was simulated by steel rods of suitable size and number. The Borax V insert did not distort significantly. In the Spert III case there was appreciable distortion, and it was decided to provide structural reinforcement rather than complicate the nuclear safety analysis.

Leak Testing

A common feature of the model tests for the casks described above was testing for leakage. Methods used were considered appropriate, taking into account the nature of the material which could leak and the regulatory requirements. For the curium cask, loss of a large percentage of the water would result in external radiation levels somewhat above regulatory limits. For the bismuth cask, a large loss of water could lead to melting of the bismuth which contains polonium; this conceivably could escape from slug cladding damaged by impact, and to a minor extent through the opening that permitted escape of water. For the PM-3A cask, the most restrictive limit was the IAEA requirement for unilaterally approved casks that no more than 0.1% of the coolant (i.e., air) should escape in one week following the accident. In all three cases the expected degree of contamination of the coolant is very low.

The tests illustrate the need for study and guidance relating to two basic questions: (1) How tight is leaktight? (2) How should one go about designing a small-scale model of a closure?

It must be recognized that absolute leaktightness or zero escape cannot be achieved. Also, it would be illogical and impractical to require the same degree of leaktightness for all radioactive materials, regardless of toxicity, physical form, or concentration. Tests which might be applied for proving leaktightness for a prototype or a design encompass a range of more than a million in relative sensitivity. Common types of closure may vary that much in their capability. Relative toxicities per unit volume for the potential leakage vary by an even larger factor. A rational basis for design and testing is urgently needed.

Some progress is being made on this. The IAEA has proposed[7] maximum leak rates which take account of the toxicity and which are considered to represent an insignificant hazard. It is nevertheless intended that good engineering and operating practice will be followed, and that actual leakage will be as low as practical. Subcommittee N-14.2.6 of the American National Standards Institute is developing recommendations on test procedures for prototypes and on the matter of providing adequate assurance that each package presented for shipment is properly assembled. Similar studies are under way in other countries.

With regard to design principles for small-scale modeling of closures, I am not aware of any basic studies in progress. A common opinion or "educated guess" among engineers is that a gasket or O-ring for a model should have the full-size cross section, and that surface roughness and runout should be unchanged. However, the magnitude of leakage and the corresponding mechanism of leakage in a particular case may be important factors. For example, if leakage develops after a 30-ft drop because of damage to the O-ring from movement of the lid, and this movement is only one-fourth as much in a model as in a prototype, then conceivably the damage and leakage could be much greater for the prototype than for the model. Similarly, the reduction of gasket or O-ring compression in the model would be less than in the prototype.

Suppose, on the other hand, that the closure is linearly modeled in all respects. This presumably includes surface roughness. Since sealing is due to forcing the gasket material to conform to surface roughness sufficiently so that every path for escape is blocked, it is not clear whether the gasket hardness should be changed. Also, if gasket damage from lateral displacement of the lid is partly dependent upon surface roughness, it is not clear that the smoother surface and lesser displacement for a model would yield valid results.

The questions and problems with closures have been mentioned not with the promise or expectation of immediate answers, but rather as a suggestion that this is an important area of shipping container design where there are large gaps in our knowledge.

SUMMARY

The Savannah River Plant has found model testing to be a very useful technique for assessing the performance of containers under impact conditions of the hypothetical accident. For complex and previously untested features of casks, such testing is considered more reliable than calculation, and frequently there is no practical alternative. As time goes on, the larger store of test results and the development of better basic data for reliable and inexpensive calculation should reduce the amount of testing which would otherwise be performed.

Much of the effort has been directed toward demonstration of adequate leaktightness. Unfortunately this is a rather nebulous area with regard to what is adequate and with regard to appropriate methods of modeling a closure. The sensitivity of tests and the degree of confidence to be established should be related to the hazard involved. Further study and technical guidance would be helpful to designers and very likely to competent authorities.

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2. H. G. Clarke, Jr., Impact Resistance of Casks, American Institute of Chemical Engineers, Nuclear Engineering Part XIV, number 56, volume 61, (1965).

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4. C. A. Wilkins, et al Design and Testing of Curium Shipping Capsule and Cask, Proceedings of the Second International Symposium on Packaging and Transportation of Radioactive Materials, October 14-18, 1968. CONF 681001. p. 344.

5. R. A. Scaggs, Upgrading of PM-3A Casks, Proceedings of Third International Symposium on Packaging and Transportation of Radioactive Materials (August 1971).

6. C. B. Clifford, Demonstration Fuel Element Shipping Cask from Laminated Uranium Metal-Testing Program, Proceedings of the Second International Symposium on Packaging and Transportation of Radioactive Materials, October 14-18, 1968. CONF 681001. p. 521.

7. Regulations for the Safe Transport of Radioactive Materials, Third Revised Draft, PL-383. International Atomic Energy Agency. November 1970.

TABLE 1. DROP TESTS OF MODEL OF CURIUM CASK

Test No.	Drop Situation	Damage Results
Drop Series I		
1	30 feet, top edge impact	Landed on lifting lug; lug buckled. Local damage of 5 fins. 3 bolts securing puncture shield broken. No damage to body shell.
2	30 feet, flat top impact	Another lifting lug deformed.
3	40 inches, top puncture	Puncture shield permanently deflected 3/8 inch. No puncture, off-center.
4	40 inches, side puncture	Local deformation of one fin; fin slightly bent. No puncture.
5	30 feet, side impact	Landed squarely on 6 fins. Body shell permanently deflected 7/16 inch max along impact line. One horizontal internal member connected to impact side of shell buckled, product capsules remained centered in shell.
6	30 feet, flat bottom impact	Some deformation of bottom fins.
7	30 feet, bottom edge impact	6 side fins smashed at bottom edge. Cask bottom slightly convex.
Drop Series II		
8	30 feet, top edge impact	No damage to new puncture shield.
9	30 feet, flat top impact	No damage to new puncture shield.
10	40 inches, top puncture	Puncture shield permanently deflected 1/2 inch. Dead-center hit.
11	15 feet, top puncture	Puncture shield permanently deflected 1¼ inches. Lid top slightly deflected. No puncture. Dead-center hit.
12	30 feet, side puncture	Sheared one fin. Bent four fins. Permanently deformed side. No puncture.
13	30 feet, top puncture	Off-center hit. Shield permanently deflected 1¼ inches max. Two puncture shield bolts sheared. Lid top permanently deflected 1/4 inch. No puncture.
14	30 feet, bottom puncture	Flat hit in center. Two fins sheared. Puncture of bottom clear through about 3/4 of pin circumference.

CURIUM SHIPPING CASK

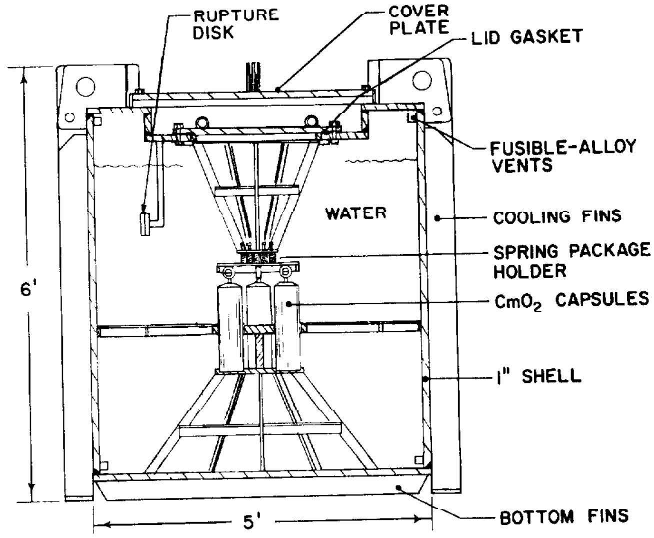


FIGURE 1

AFTER DROP NO. 1

FIGURE 2

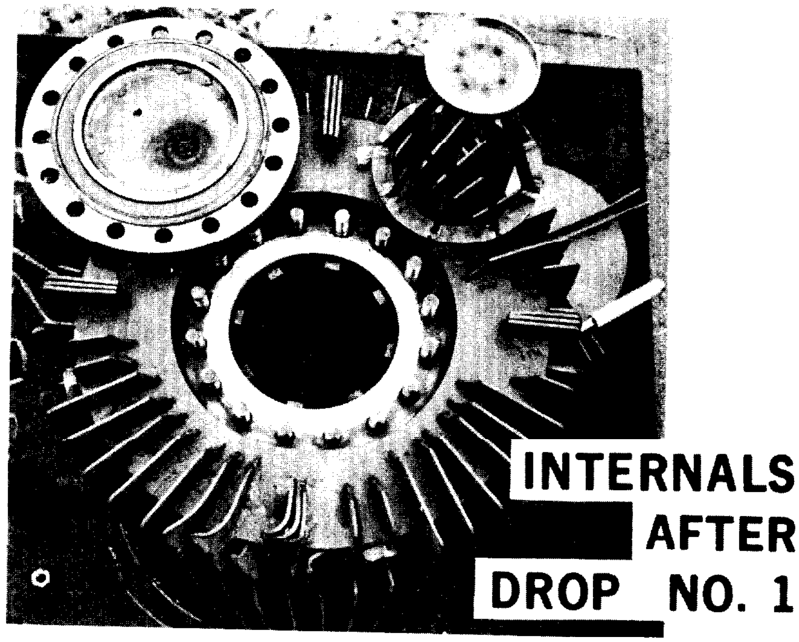
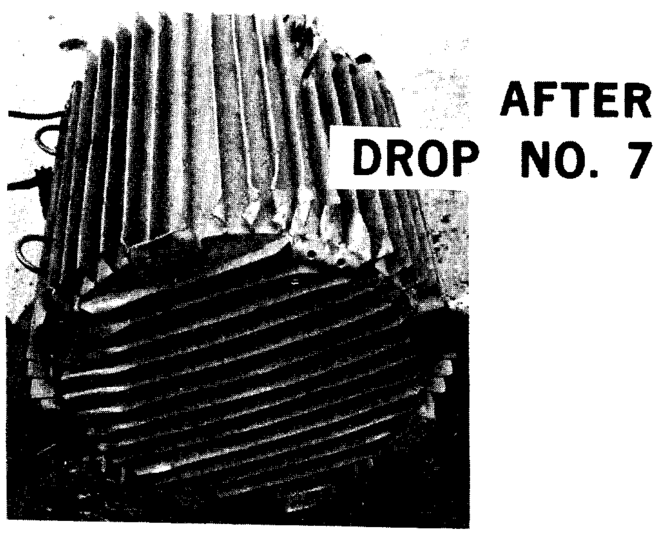


FIGURE 3



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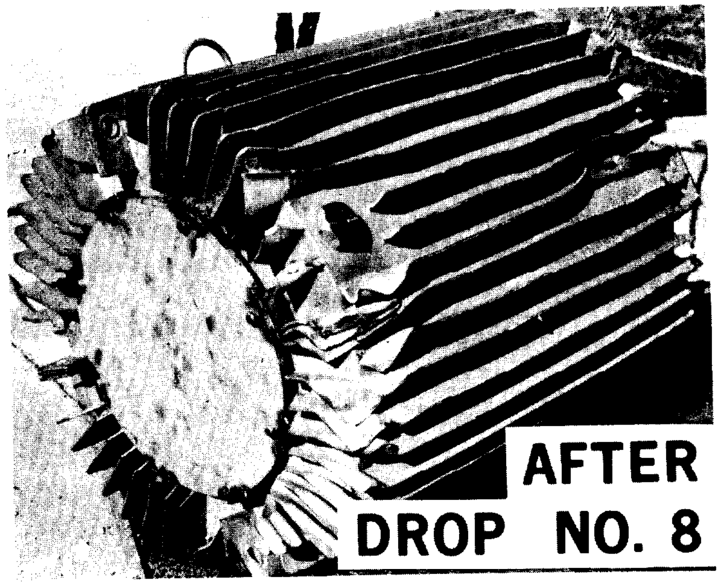
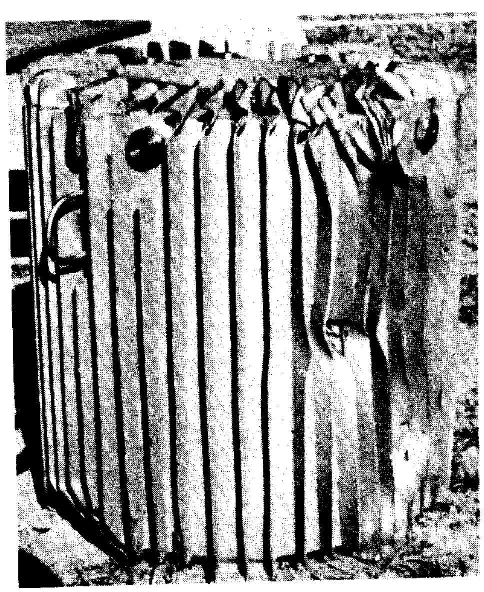


FIGURE 5



AFTER
DROP
NO 12

FIGURE 6

FIGURE 7

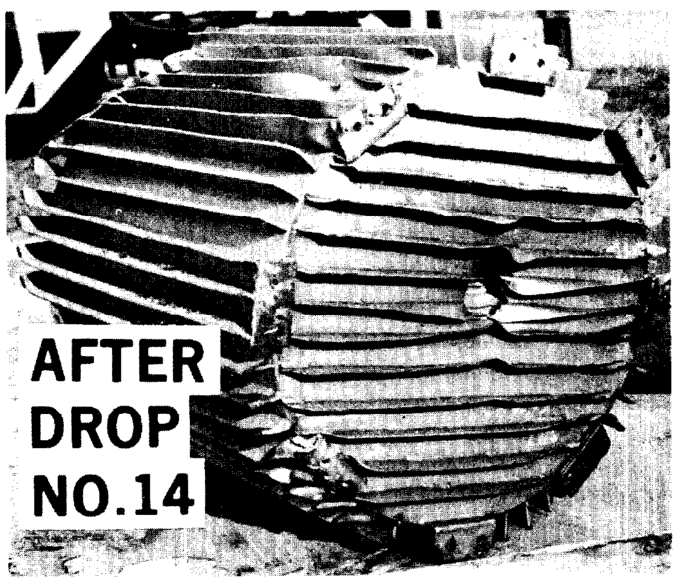


FIGURE 8

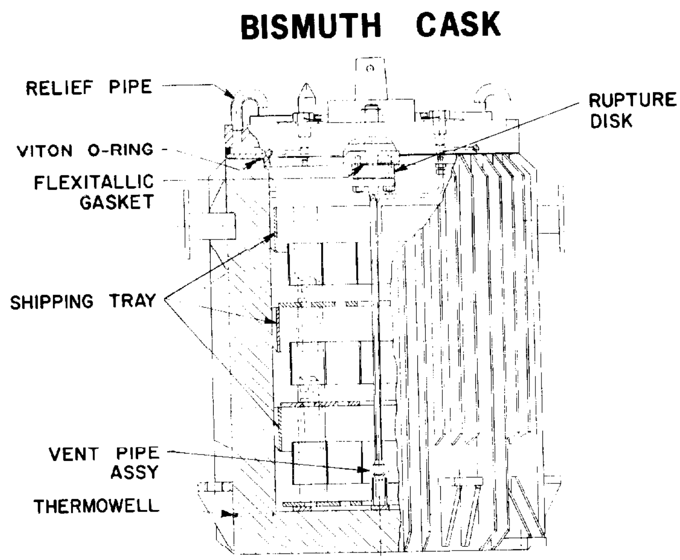


FIGURE 9

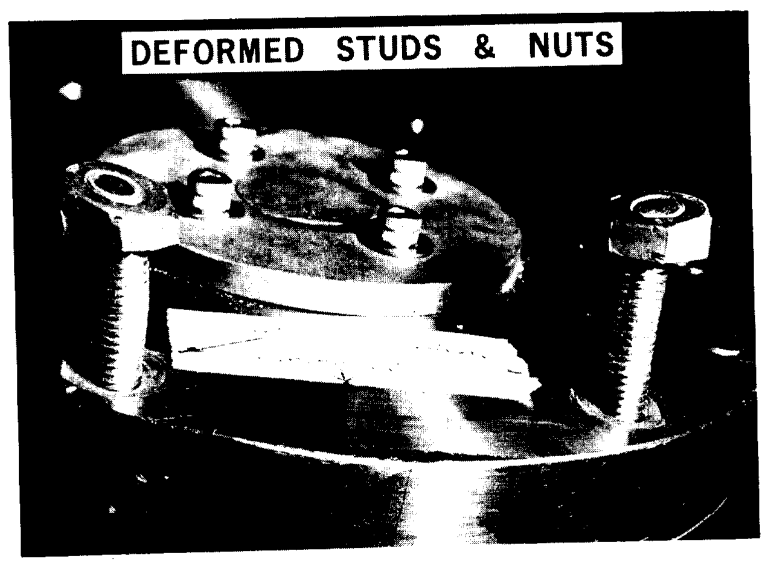


FIGURE 10

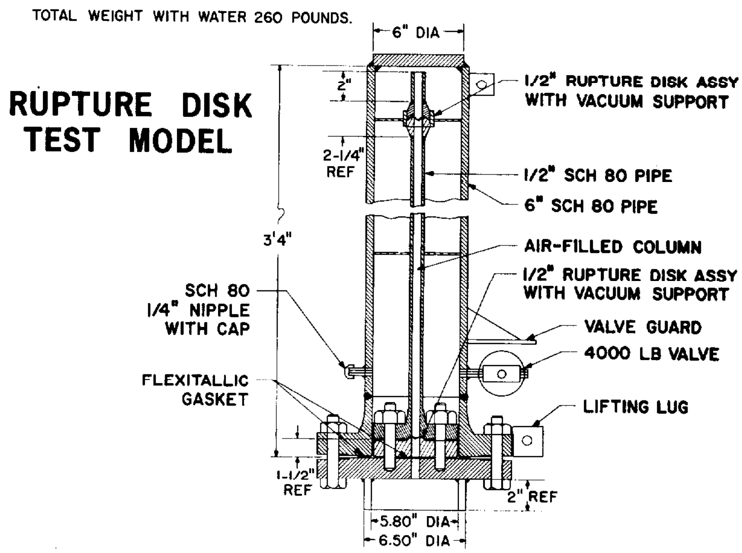


FIGURE 11

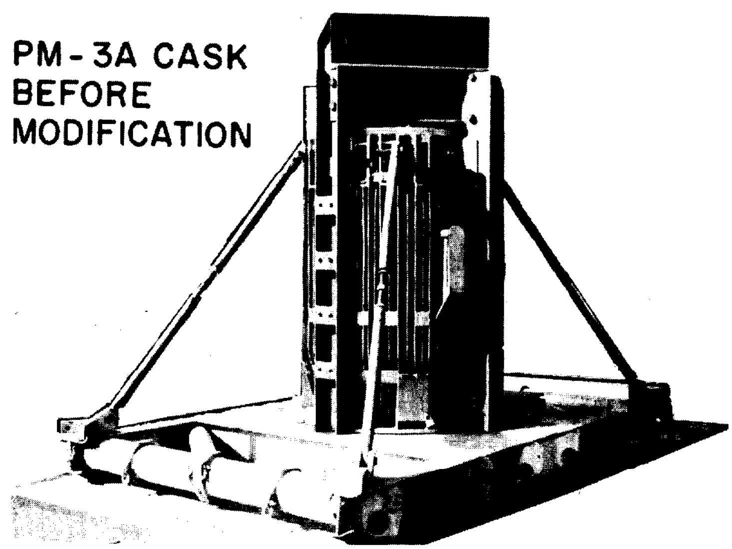
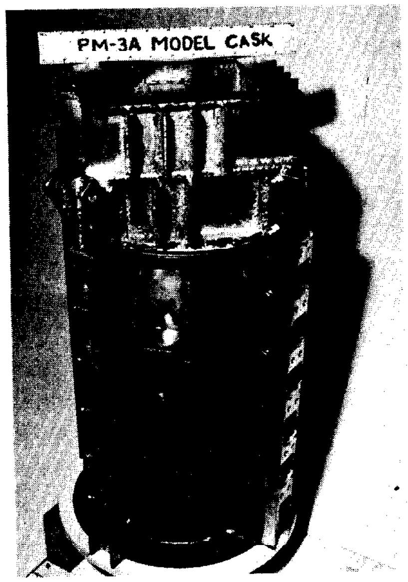
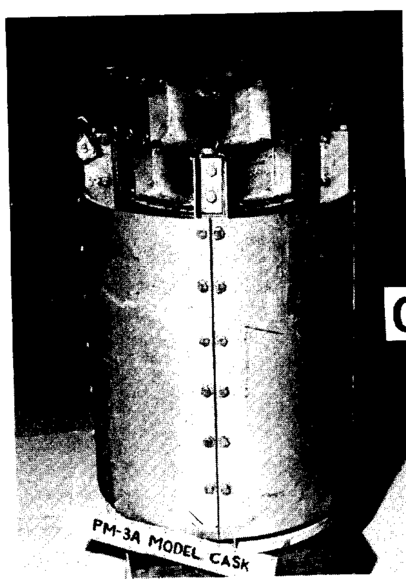


FIGURE 12



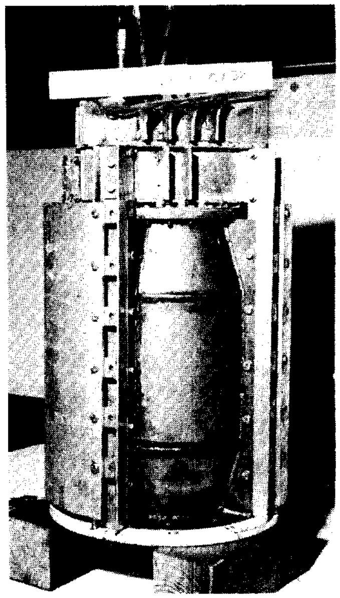
MODEL WITH SHROUDS REMOVED

FIGURE 13



DAMAGE FROM TOP CORNER DROP

FIGURE 14



ONE SHROUD SECTION REMOVED

FIGURE 15

BOTTOM CORNER DROP

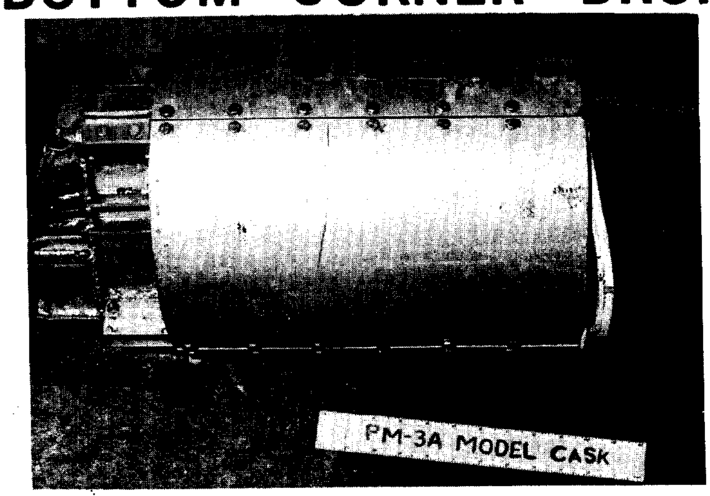


FIGURE 16

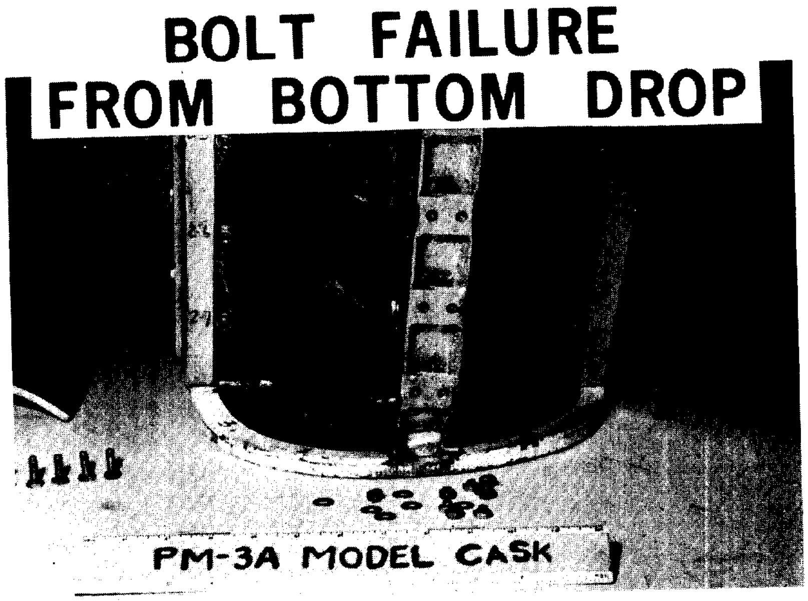


FIGURE 17

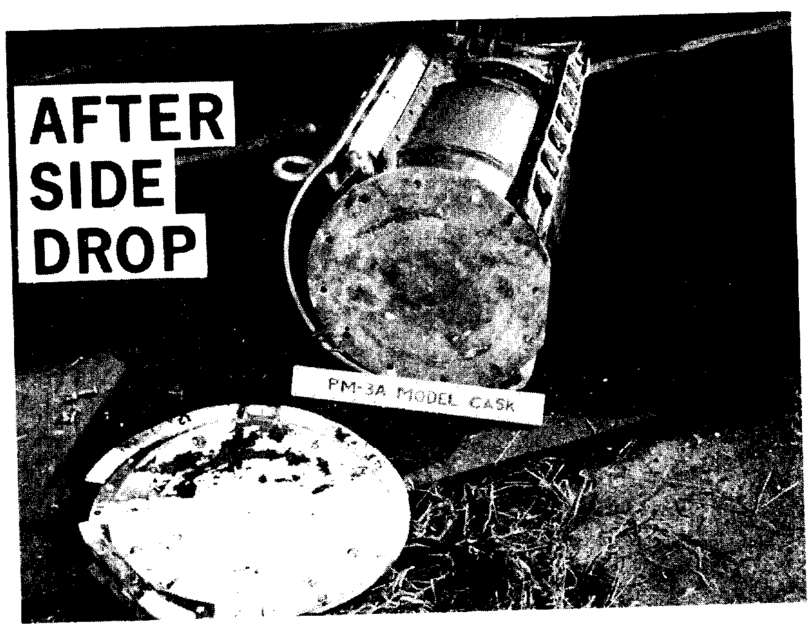


FIGURE 18

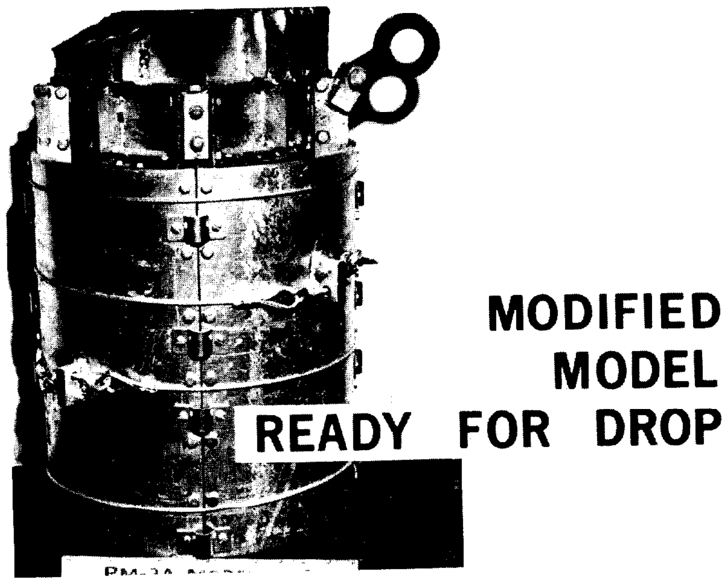


FIGURE 19

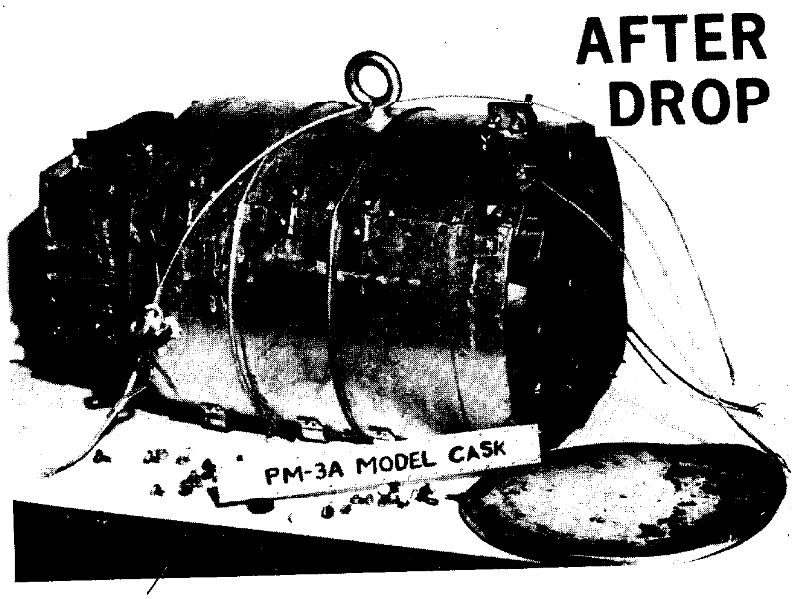


FIGURE 20