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A Highway Accident Involving Radiopharmaceuticals Near Brookhaven, Mississippi on December 3, 1983

Peter B. Mohr, Mark E. Mount, and Martin W. Schwartz

Prepared for
U.S. Nuclear Regulatory Commission

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ABSTRACT

A rear-end collision occurred between a passenger automobile and a luggage trailer carrying 84 packages, 76 of which contained radiopharmaceuticals, on U.S. Highway 84 near Brookhaven, Mississippi on the afternoon of December 3, 1983. The purpose of this report is to document the mechanical circumstances of the accident, confirm the nature and quantity of radioactive materials involved, and assess the nature of the physical environment to which the packages were exposed and the response of the packages.

The report consists of three major sections. The first deals with the nature and circumstances of the accident and findings of fact. The second gives an accounting and description of the materials involved and the consequences of their exposure. The third gives an assessment and analysis of the mechanisms of damage and the conclusions which may be drawn from the investigation.

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EXECUTIVE SUMMARY

An inquiry, assessment, and analysis were performed of a highway accident involving a rear-end collision at high speed between a passenger car and a luggage trailer in courier service transporting 84 packages, 76 of which contained radiopharmaceuticals with a total inventory of 54.774511 Ci. The accident occurred on a rural section of U.S. Highway 84 near Brookhaven, Mississippi, under conditions of light, intermittent rain showers at about 4:00 p.m. on the afternoon of December 3, 1983.

In the collision, the trailer was destroyed and the 84 packages were dispersed to both sides of the highway over a distance of approximately 250 yards. Thirty of the 76 radiopharmaceutical packages were damaged to the extent that their outer packaging was destroyed; the balance had their outer packaging intact. Two of these 30 packages, one with ^{67}Ga and the other with ^{131}I and both at millicurie levels, had their radioactive-material containment vessels (vials) ejected from their shielding and subsequently broken. The ^{67}Ga was found to the right of the centerline of the highway within the confines of its damaged outer package. The ^{131}I was on the same side, but approximately 15 to 20 feet farther east, off the hard shoulder and on the rough gravel. The vial was essentially obliterated and there was no evidence of the damaged package nearby. Control of the site was effected promptly, and full cleanup was accomplished by early the following morning. There were no injuries or personal contamination.

The mechanisms and procedures for assuring public safety and implementing prompt cleanup and recovery appear to have functioned with appropriate promptness and effectiveness.

It was determined that the transporting vehicle, a light luggage trailer, failed to provide any substantial physical protection to the cargo. Even though it is recognized that Type A packages do not have to withstand severe accident loadings, it appears that some simple inexpensive measures could reduce the possibility of radioactive release. If lead shields are to be secured with tape or shrink bands, it would be more effective if a fiberglass-reinforced tape were used and the shields were wrapped in an axial rather than circumferential direction. It is also suggested that additional packing material be added to prevent impact of the glass containment vessels on the side of the lead shield and to more effectively absorb radioactive liquids in the event of containment vessel fractures. Furthermore, it is suggested that a metal pin replace the polypropylene shear pin on the Squibb design to maintain the integrity of the lead shield.

The practice of recording the calibration level of activity on the bill of lading instead of the maximum activity at any time during transportation appears to be in violation of 49 CFR 172.203(d)(iii).

INTRODUCTION

Background

Every week in the U.S., large quantities--tens of thousands of packages--of essential radiopharmaceuticals are distributed. Because the radioactive components of these materials are intentionally chosen to be of short half-life, this distribution must be prompt and regular. The terminal portion of this distribution is an elaborate highway courier network which reaches the most remote medical facilities and hospitals. This network radiates from regional distribution centers, from which large highway semitrailer units carrying from one to a few thousand packages rendezvous with local couriers within perhaps a 500-mile radius. These local couriers, in turn, distribute to the destination points, delivering about 100 packages to 30 destinations in a 250-mile radius within a 2-day period.

Objectives

The purpose of this report is to document the mechanical circumstances of a highway accident involving one of these courier vehicles on December 3, 1983. In this accident 84 packages, 76 of which contained radiopharmaceuticals, were dispersed along a public highway and damaged to varying degrees. Two of the packages released their radioactive-material containment vessels from their lead shielding and were destroyed, releasing millicurie quantities of short-lived (half-life less than 9 days) radiopharmaceuticals. The specific objectives can be summarized as follows:

- a. Confirm the circumstances of the accident.
- b. Document procedures used for cleanup and for safety.
- c. Describe the response of packages and transport vehicles.
- d. Characterize and quantify the damage and damage mechanisms.

Fact-Finding Trip

On December 9, 1983, three technical representatives from LLNL visited the accident scene near Brookhaven, Mississippi and conferred with the Director and staff of the Division of Radiological Health (DRH) of the Mississippi State Department of Health in Jackson. Information concerning initial response to the accident was obtained from Mr. Eddie S. Fuente, Director of the DRH and his staff. After this briefing, Mr. Fuente offered the services of one of his deputies, Mr. Gregg Dempsey, to accompany the LLNL personnel to the site of the accident. While in the Brookhaven area the LLNL team gathered information from the Brookhaven Police and Sheriff's office, the Mississippi Highway Patrol district office, and the Lincoln County Civil Defense Director (Brookhaven area).

On the following day, Saturday, December 10, two of the LLNL team members joined Mr. Fuente and another of his deputies, Mr. Michael J. Smith, in witnessing the transfer of a scheduled shipment of radiopharmaceuticals from the semitrailer of Associated Couriers, Inc. to two van-trailer caravans also provided by Associated (Fig. 1). One of the trailers used was identical to that destroyed in the accident the previous week (Fig. 2). The transfer was conducted in the parking lot of the Ryder truck depot on the outskirts of Jackson. Following transfer, both caravans were subjected to a radiological survey by both the operators and DRH (Fig. 3).

Figure 1. Van-trailer caravan loading operations in Jackson, Mississippi on December 10, 1983.

Figure 2. Trailer of the type involved in the accident near Brookhaven, Mississippi on December 3, 1983.

Figure 3. Associated Couriers, Inc. driver and DRH staff member performing a survey of a loaded trailer in Jackson, Mississippi on December 10, 1983.

On Sunday, December 11, the same two LLNL team members traveled to Saint Louis, Missouri to meet the representatives of Mallinckrodt, Inc., the cleanup team, and Associated Couriers, Inc. At this time it was possible to view and to make limited photographs of the recovered materials.

After returning to LLNL, the team members conducted substantial communication and correspondence with representatives of the pharmaceutical companies, the DRH, and various individual witnesses.

ACCIDENT DESCRIPTION

Circumstances

The courier caravan onto which the packages were transferred from the distribution semitrailer at Jackson on December 3 was towed by a 1982 Chevrolet Carryall (truck-based station wagon) equipped to tow a utility (luggage) trailer. In this instance, all the packages were placed in the trailer and none in the towing vehicle, to minimize exposure to the driver. The Carryall was equipped with a full shield installed at the forward end of the cargo space, behind the drivers' seats. On leaving Jackson sometime after noon, the couriers proceeded south until they intercepted Mississippi State Highway 27 (Fig. 4), then they moved in a southeastern direction to the town of Monticello, where the first delivery was made. They then continued west along U.S. Highway 84 toward Brookhaven, where a second delivery was scheduled. The weather had been overcast, with intermittent rain throughout most of the afternoon.

The Accident Site

The accident site was a portion of the westbound lanes of U.S. Highway 84, just east of the intersection with Ruth Road, southeast of the town of Brookhaven (Figs. 4-6). In this location, the highway is four-lane, divided with a broad level median and with level to gently sloping shoulders. The site of the initial impact was at the beginning of a straight, relatively level stretch of the highway extending over approximately 300 yards. The approach from the east was over a gentle rise with a grade not more than 1%. The departure to the west was a slight rise from 1 to 2% approaching the intersection with Ruth Road. The condition of the road is good; traction is good and there are no visual obstructions or distractions. At the time of our visit to the site, December 9, the residual evidence of the accident six days earlier was a scattering of fragmented plastic foam packaging and occasional pieces of saline bottles and stoppers. At the time of the accident, the conditions of the site were described by all witnesses interviewed as generally clear but damp, and with intermittent showers.

Description of the Accident

The principal references for the description of the accident are the Mississippi State Highway Patrol Accident Report No. 910382, filed on December 9, and interviews with the driver and co-driver of the towing vehicle at the time of the accident. Other interviews were conducted with early-arriving witnesses, all from the Brookhaven area. No interview was attempted with the driver of the overtaking vehicle who was, at the time of our visit, under detention on charges resulting from the accident.

According to the Highway Patrol report, the driver, and other witnesses, the vehicle caravan transporting the radiopharmaceuticals was in the curb lane of westbound U.S. 84, traveling at about 50 to 55 mph at approximately 4:00 p.m. The driver of the vehicle caravan described it as having just emerged from a rain shower on a gentle downgrade, approaching a level stretch. The relief driver was in the right-hand passenger seat, reading and not paying particular attention to the surroundings. Both described the moment of impact as unexpected; the overtaking vehicle had apparently not been noticed. The effect of the impact was described as a "lurching" sensation followed by a jolt and crash. The driver apparently had no difficulty in bringing the vehicle to a stop and only then realized that the luggage trailer had been torn from the Carryall and lay demolished beneath the Oldsmobile sedan some distance, perhaps 75 yards back on the highway. A portion of the trailer frame was still attached to the hitch of the Carryall.

Figure 4. Map of the area around Jackson, Mississippi.

Figure 5. Drawing of the accident scene near Brookhaven, Mississippi.

Figure 6. Accident scene near Brookhaven, Mississippi, in a view to the west. The photograph was taken on December 9, 1983.

A total of 84 packages (76 containing radiopharmaceuticals) was dispersed to both sides of the highway over a distance of approximately 250 yards. Thirty of the 76 radiopharmaceutical packages were damaged to the extent that their outer packaging was destroyed; the rest had their outer packaging intact. Two of these 30 packages, one with 0.00468 Ci of ^{67}Ga and the other with 0.00165 Ci of ^{131}I , had their radioactive-material containment vessels (vials) ejected from their shielding and subsequently broken. The ^{67}Ga source was found to the right of the centerline of the highway within the confines of its damaged outer package. The ^{131}I was on the same side, but approximately 15 to 20 feet farther east, off the hard shoulder and on the rough gravel. The vial was essentially obliterated and there was no evidence of the damaged package nearby.

Description of the Vehicles

The damage to the Carryall was found to be relatively minor although one of the ^{131}I packages had been catapulted through one of the windows of the rear panel doors. The doors themselves were caved in slightly at the midline, as was the rear bumper and hitch.

The overtaking vehicle, a 1976 Oldsmobile Model 98 sedan (Fig. 7) was perched astride the remains of the trailer floor and axle. The driver and his single passenger appeared to be unhurt. The damage to the Oldsmobile was principally cosmetic, limited to the front-end decorative work, hood, fender, and windshield, equivalent to a barrier crash at not more than 15 mph. The trailer was demolished. All the cargo had been ejected along the highway, the cover torn away, the front frame torn off, one wheel crushed, and a tire torn loose (Fig. 8).

Postaccident Safety Procedures

Shortly after the accident, the relief driver made contact with the Mississippi State Highway Patrol, and through it, with the Mississippi Emergency Management Agency (MEMA), via a citizens band radio from a pickup truck that was the first to arrive at the scene. A local resident reports arriving within 2 to 3 minutes after the accident and being stopped at least 100 yards from the scene by the driver of a pickup truck. At approximately 4:10 p.m. (CST), a Highway Patrol unit dispatched to the scene from a district office near Brookhaven arrived. Within 10 minutes after arrival of the first Highway Patrol officer, the witness reports the arrival of another three Highway Patrol officers and an undetermined number of other peace officers (sheriff and/or police). Also arriving at the scene was the Lincoln County Civil Defense Director. A few minutes later, a unit from the Brookhaven Fire Department arrived. Firefighters were reported to have donned protective clothing and breathing apparatuses. The Civil Defense Director made a survey of the accident scene and reported the exposure level at "five roentgens on a scale of 1000" (this is interpreted to mean 5 mR). A short time later, the Civil Defense Director and the courier service driver left the accident scene so that the driver could make the calls required by his emergency procedures.

At approximately 4:15 p.m. (CST), Mr. Eddie S. Fuente, Director of the Division of Radiological Health (DRH), Mississippi State Department of Health, was notified of the accident by MEMA. After contacting key personnel, Mr. Fuente and three of his deputies left Jackson for Brookhaven in a mobile emergency unit, at approximately 5 p.m. (CST). By 5:50 p.m. (CST) Mr. Fuente and staff were at the accident scene.

Figure 7. 1976 Oldsmobile sedan perched astride the remains of the trailer floor and axle at the accident scene near Brookhaven, Mississippi on December 3, 1983.

Figure 8. Remains of trailer floor, axle, and cover at the accident scene near Brookhaven, Mississippi on December 4, 1983.

By the time the staff of the DRH arrived, the area had already been cordoned off by the Highway Patrol. DRH staff looked over the accident scene, prepared an inventory of the sources involved in the accident from the shippers' bills of lading, and conducted an extensive survey of the area with an Eberline E-520 (HP-270 probe). Also surveyed were the emergency vehicles at the scene, the Civil Defense and Highway Patrol Officers, the trailer remnants, and the damaged automobile. No activity was found on any of the above and the area survey indicated no public health hazard. A decision was then made by Mr. Fuente that the cleanup would be accomplished by personnel provided by the courier service and radiopharmaceutical shippers.

Of the five radiopharmaceutical shippers whose packages were in the shipment, New England Nuclear sent one representative and Mallinckrodt sent four, one of whom was acting as a consultant for Associated Couriers. The New England Nuclear representative arrived on the scene at approximately 2:30 a.m. (CST) on Sunday, December 4, 1983. Mallinckrodt and Associated Couriers representatives were on the scene by 3:30 a.m. (CST); they further agreed to supply the DRH staff with a complete inventory of the materials recovered from the accident scene.

Cleanup and Removal

For approximately the next 2-3/4 hours, representatives of DRH, New England Nuclear, Mallinckrodt, and Associated Couriers went about the task of cleaning up the debris. Small debris and packing materials were placed in plastic bags and then into cardboard boxes and set at the side of the road. Damaged and undamaged packages were also put in cardboard boxes and placed at the side of the road. In the area where the ^{131}I source was found broken, approximately 3 cubic feet of topsoil was removed and placed in three to four boxes and set at the side of the road.

Starting at about 5:30 a.m. (CST) and continuing for approximately 1 hour, a local wrecker service removed the remnants of the trailer and damaged automobile from the accident scene.

At approximately 6:15 a.m. (CST) a U-Haul truck, rented by Associated Couriers, arrived and was loaded with the accident debris and contaminated topsoil (Fig. 9). DRH staff surveyed the U-Haul truck and the Carryall driven by the courier service before allowing them to leave the area, and ensured they were marked appropriately.

At approximately 7 a.m. (CST) DRH staff began a survey of the area to about 100 feet on both sides of the highway with a Ludlum μR meter (Model 19) to confirm that the cleanup was complete. Background radiation was on the order of 8 to 12 μR .

Between 7:20 and 8 a.m. (CST) the highway and two spill sites were washed down with approximately 1000 gallons of water by a unit of the Brookhaven Fire Department. A subsequent survey of the spill sites showed readings of approximately 100 and 250 μR at one meter for the ^{67}Ga and ^{131}I locations, respectively.

Shortly after at 8 a.m. (CST) the highway was released to public use.

Figure 9. U-Haul truck being loaded with accident debris and contaminated topsoil near Brookhaven, Mississippi on December 4, 1983.

DESCRIPTION OF THE PACKAGES

At the time of the accident, there were 79 packages remaining to be delivered and 5 packages containing depleted returns: 76 packages of radiopharmaceuticals (67 radioactive material and 9 radioactive material, limited quantity) and 8 packages containing either medical supplies, drugs and medicines, or diagnostic kits. Table 1 presents a summary of the radionuclides and their half-lives. Table 2 presents a summary of the pertinent characteristics of the radioactive materials and their packaging. Since a detailed description of each shipper's package would make Table 2 excessively long, a notation system was adopted for the package description to make the table more manageable. Immediately following Table 2 are the detailed package descriptions arranged by shipper and notation.

The total activity present, based upon the shippers' bills of lading, was 54.77398 Ci. After reconstruction and taking into account the nonspecified limited quantities, the total activity was adjusted to 54.774511 Ci. The actual amount of activity present at the time of the accident was undoubtedly higher; at least one shipper has stated that the activity reported on their shipping documents is that required at the customer-specified calibration (reference) date and not necessarily the activity present at the time of shipping. This appears to be in violation of 49 CFR 172.203(d)(iii). Totals for the transport index and weight of the 76 radioactive material packages were 97.1 and 1287 to 1377 lb, respectively. Total weight for the eight packages with nonradioactive contents was 28 lb. The fact that the total transport index of 97.1 exceeds the value of 50 specified in 49 CFR 177.842 is of no consequence here. Associated Couriers is a party to DOT exemption E 8308, which allows $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ generators to be excluded from the computation of the total transport index. Since the total transport index associated with the $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ generators was 82.6, the total transport index for the shipment under the provisions of E 8308 was 14.5.

The following paragraphs summarize the contents of Table 2 on a nuclide basis.

Two packages containing 0.000250 Ci each of ^3H in liquid form and shipped as limited quantities were among the packages shipped by New England Nuclear. Activity and weight totals for these limited-quantity packages were 0.0005 Ci and 2 lb, respectively.

The ^{32}P was present in two packages in liquid form, had a total activity of 0.01 Ci, and was shipped by Mallinckrodt. The total transport index and weight for the two packages was 0.2 and 3 lb, respectively.

Nine packages contained ^{67}Ga in a liquid form; total activity was 0.62 Ci. Six packages, containing 0.602 Ci, were shipped by New England Nuclear; the remainder were shipped by Mallinckrodt. Total transport index and weight for the nine packages were 6.9 and 50 lb, respectively. Of these totals, the New England Nuclear packages represented 6.3 and 44 lb.

The ^{99}Mo was in solid form and is in equilibrium with its daughter, $^{99\text{m}}\text{Tc}$. It is packaged as a generator for $^{99\text{m}}\text{Tc}$. There were a total of 28 new generators from four different suppliers with totals in activity, transport index, and weight of 50.801 Ci, 82.6, and 981 lb, respectively. Mallinckrodt supplied 12 generators with totals in activity, transport index, and weight of 15.75 Ci, 21.5, and 398 lb. The eight generators shipped by New England Nuclear had totals in activity, transport index, and weight of 19.375 Ci, 29.8, and 320 lb. Squibb supplied seven generators. Totals in activity, transport index, and weight

for the Squibb generators were 12.366 Ci, 28.8, and 215 lb. The single generator supplied by Cintichem, Inc., had an activity of 3.31 Ci, a transport index of 2.5, and a weight of 48 lb. There were also five used Mallinckrodt generators containing depleted returns with activities at or below the limited quantity value (0.020 Ci). Since the activity levels and weights for each of these packages were unknown, the limited quantity limit (0.020 Ci) and package weight range (27 to 45 lb) was assumed. Thus, the used Mallinckrodt generators added 0.100 Ci to the total activity and 135 to 225 lb to the total cargo weight.

A single package containing 0.00006 Ci of ^{125}I in liquid form and shipped as a limited quantity was also among the packages shipped by Mallinckrodt. Total weight of this limited quantity package was 2 lb.

The ^{131}I was present in 13 packages provided by two suppliers. It was both in solid and liquid form, and had totals in activity, transport index, and weight of 0.47992 Ci, 6.5, and 68 lb, respectively. The nine packages supplied by Mallinckrodt contained the ^{131}I in either liquid or encapsulated liquid form or both. Totals in activity, transport index, and weight for the Mallinckrodt packages were 0.333575 Ci, 4.8, and 53 lb. Squibb supplied the four remaining packages, two of which contained the ^{131}I in encapsulated solid form. For the encapsulated solid packages, the totals in activity, transport index, and weight were 0.001706 Ci, 0.4, and 4 lb. The two Squibb packages with ^{131}I in liquid form had totals in activity, transport index, and weight of 0.144639 Ci, 1.3, and 11 lb.

The ^{133}Xe was present in a gaseous form in uncompressed conditions. A total of 12 packages of ^{133}Xe were present at the time of the incident. Totals in activity, transport index, and weight for the ^{133}Xe packages were 2.724 Ci, 0.8, and 34 lb, respectively. Mallinckrodt supplied seven of the packages, New England Nuclear supplied four, and Medi-Physics supplied one. The Mallinckrodt packages had totals in activity, transport index, and weight of 0.3 Ci, 0.7, and 11 lb. Totals in activity, transport index, and weight for the New England Nuclear packages were 2.364 Ci, 0.1, and 21 lb. The single ^{133}Xe package supplied by Medi-Physics had a total activity of 0.06 Ci, a transport index of 0.0, and a weight of 2 lb.

A single package containing 0.000031 Ci of ^{137}Cs in liquid form and shipped as a limited quantity was also part of the New England Nuclear shipment. Total weight of this limited quantity package was 3 lb.

Three packages containing ^{201}Tl in liquid form made up the balance of the shipment at the time of the accident. Totals in activity, transport index, and weight for these packages were 0.039 Ci, 0.1, and 9 lb, respectively. The two packages supplied by New England Nuclear had a total activity of 0.035 Ci, a transport index of 0.0, and a weight of 8 lb. The single package shipped by Medi-Physics had 0.004 Ci of activity, a transport index of 0.1, and weighed 1 lb.

Arrangement of Packages

In arranging the packages in the trailer, first priority was apparently given to fit. After packaging for fit, priority was given to convenience of package removal upon delivery. Arrangement of the packages with respect to transport index was not a consideration. No special measures were taken to tie down the packages.

Table 1. Radionuclides present in the radiopharmaceutical packages, and their half-lives.

Nuclide	Half-life (days)
^3H	4503.5
^{32}P	14.28
^{67}Ga	3.26
^{99}Mo	2.75
$^{99\text{m}}\text{Tc}$	0.25
^{125}I	60.2
^{131}I	8.04
^{133}Xe	5.25
^{137}Cs	11019.6
^{201}Tl	3.04

Table 2. Description of the radioactive-material packages involved in the accident near Brookhaven, Mississippi on December 3, 1983.

Nuclide	Activity (Ci) ^a	Physical form	Chemical form	Transport index	Package weight (lb)	Shipper package description
³ H	0.000250	Liquid	Labeled testosterone	NA ^b	1	NEN note 1
	0.000250	Liquid	Labeled corticosterone	NA ^b	1	NEN note 1
	Subtotal	0.000500			2	
³² P	0.005	Liquid	Sodium phosphate	0.1	1	Mal note 1
	0.005	Liquid	Sodium phosphate	0.1	2	Mal note 1
	Subtotal	0.010		0.2	3	
⁶⁷ Ga	0.006	Liquid	Gallium citrate	0.2	2	Mal note 2
	0.006	Liquid	Gallium citrate	0.2	2	Mal note 2
	0.006	Liquid	Gallium citrate	0.2	2	Mal note 2
	0.019	Liquid	Gallium citrate	0.1	3	NEN note 2
	0.019	Liquid	Gallium citrate	0.1	3	NEN note 2
	0.325	Liquid	Gallium citrate	2.0	22	NEN note 2
	0.029	Liquid	Gallium citrate	0.1	3	NEN note 2
	0.115	Liquid	Gallium citrate	2.0	7	NEN note 2
	0.089	Liquid	Gallium citrate	2.0	6	NEN note 2
	0.006 ^c	Liquid	Gallium citrate	--	--	NEN note 2
	Subtotal	0.620		6.9	50	
⁹⁹ Mo	2.0	Solid	Sodium molybdate	2.3	35	Mal generator
	3.0	Solid	Sodium molybdate	2.5	45	Mal generator
	1.0	Solid	Sodium molybdate	1.2	35	Mal generator
	0.5	Solid	Sodium molybdate	1.5	27	Mal generator
	1.0	Solid	Sodium molybdate	1.2	35	Mal generator
	2.0	Solid	Sodium molybdate	2.3	35	Mal generator
	1.5	Solid	Sodium molybdate	1.7	35	Mal generator
	0.5	Solid	Sodium molybdate	1.5	27	Mal generator
	2.0	Solid	Sodium molybdate	2.3	35	Mal generator
	0.5	Solid	Sodium molybdate	1.5	27	Mal generator
	0.75	Solid	Sodium molybdate	2.3	27	Mal generator
	1.0	Solid	Sodium molybdate	1.2	35	Mal generator
	0.020 ^d	Solid	Sodium molybdate	NA ^b	27-45 ^e	Mal generator ^f
	0.020 ^d	Solid	Sodium molybdate	NA ^b	27-45 ^e	Mal generator ^f
	0.020 ^d	Solid	Sodium molybdate	NA ^b	27-45 ^e	Mal generator ^f
	0.020 ^d	Solid	Sodium molybdate	NA ^b	27-45 ^e	Mal generator ^f
	0.020 ^d	Solid	Sodium molybdate	NA ^b	27-45 ^e	Mal generator ^f

Table 2. (Continued.)

Nuclide	Activity (Ci) ^a	Physical form	Chemical form	Transport index	Package weight (lb)	Shipper package description
⁹⁹ Mo (cont)	0.745	Solid	Salt	2.5	30	NEN generator
	2.981	Solid	Salt	4.0	50	NEN generator
	3.726	Solid	Salt	4.5	50	NEN generator
	4.471	Solid	Salt	5.0	50	NEN generator
	1.490	Solid	Salt	4.0	30	NEN generator
	0.373	Solid	Salt	1.3	30	NEN generator
	1.118	Solid	Salt	3.5	30	NEN generator
	4.471	Solid	Salt	5.0	50	NEN generator
	2.190	Solid	Molybdate	5.4	29	ERS generator
	1.449	Solid	Molybdate	4.0	29	ERS generator
	0.725	Solid	Molybdate	2.0	29	ERS generator
	2.914	Solid	Molybdate	4.0	41	ERS generator
	1.449	Solid	Molybdate	4.0	29	ERS generator
	1.449	Solid	Molybdate	4.0	29	ERS generator
	2.190	Solid	Molybdate	5.4	29	ERS generator
	3.310	Solid	Sodium molybdate	2.5	48	Cin generator
Subtotal 50.901				82.6	1116-1206	
¹²⁵ I	0.000060	Liquid	Sodium iodide	NA ^b	2	Mal note 3
¹³¹ I	0.140	Liquid	Sodium iodide	1.2	18	Mal note 4
	0.0099	Liquid	Sodium iodide	--	--	Mal note 4
	0.0254	Encapsulated liquid	Sodium iodide	0.9	4	Mal note 5
	0.001	Liquid	Sodium iodide	0.2	2	Mal note 2
	0.1401	Encapsulated liquid	Sodium iodide	1.4	10	Mal note 5
	0.0099	Encapsulated liquid	Sodium iodide	--	--	Mal note 5
	0.001	Liquid	Sodium iodohippurate	0.2	2	Mal note 2
	0.0005	Liquid	Sodium iodohippurate	0.2	1	Mal note 2
	0.00045	Encapsulated liquid	Sodium iodide	0.1	4	Mal note 5
	0.004	Liquid	Sodium iodohippurate	0.5	10	Mal note 2
	0.001 ^c	Liquid	Sodium iodohippurate	--	--	Mal note 2
	0.000075	Encapsulated liquid	Sodium iodide	--	--	Mal note 5

Table 2. (Continued.)

Nuclide	Activity (Ci) ^a	Physical form	Chemical form	Transport index	Package weight (lb)	Shipper package description
¹³¹ I (cont)	0.00025	Encapsulated liquid	Sodium iodide	0.1	2	Mal note 5
	0.000853	Encapsulated solid	Sodium iodide	0.2	2	ERS note 1
	0.000853	Encapsulated solid	Sodium iodide	0.2	2	ERS note 1
	0.136983	Liquid	Sodium iodide	0.9	7	ERS note 2
	0.007656	Liquid	Sodium iodohippurate	0.4	4	ERS note 3
Subtotal	0.47992			6.5	68	
¹³³ Xe	0.050	Uncompressed gas	Xenon gas	0.1	1	Mal note 6
	0.060	Uncompressed gas	Xenon gas	0.1	2	Mal note 6
	0.050	Uncompressed gas	Xenon gas	0.1	2	Mal note 6
	0.050	Uncompressed gas	Xenon gas	0.1	1	Mal note 6
	0.020	Uncompressed gas	Xenon gas	0.1	1	Mal note 6
	0.040	Uncompressed gas	Xenon gas	0.1	2	Mal note 6
	0.030	Uncompressed gas	Xenon gas	0.1	2	Mal note 6
	0.110	Uncompressed gas	Xenon gas	0.0	2	NEN note 3
	1.989	Uncompressed gas	Xenon gas	0.1	16	NEN note 3
	0.044	Uncompressed gas	Xenon gas	0.0	1	NEN note 3
	0.221	Uncompressed gas	Xenon gas	0.0	2	NEN note 3
	0.060	Uncompressed gas	Xenon gas	0.0	2	Med note 1
Subtotal	2.724			0.8	34	
¹³⁷ Cs	0.000031	Liquid	Salt	NA ^b	3	NEN note 2
²⁰¹ Tl	0.005	Liquid	Salt	0.0	3	NEN note 2
	0.030	Liquid	Salt	0.0	5	NEN note 2
	0.002	Liquid	Thallous chloride	0.1	1	Med note 2

Table 2. (Continued.)

Nuclide	Activity (Ci) ^a	Physical form	Chemical form	Transport index	Package weight (lb)	Shipper package description
	0.002	Liquid	Thallous chloride	--	--	Med note 2
Subtotal	0.039			0.1	9	
Grand total	54.774511			97.1	1287-1377	

^a Activities presented are those appearing on the shippers' bills of lading or otherwise reconstructed.

^b Limited quantity.

^c Package containing this material failed, resulting in contamination to local environment.

^d Depleted return. Activity assumed is limited-quantity value.

^e Specific weight of returned generator package unknown.

^f Quality of repackaging unknown.

NEN - New England Nuclear Corp.

Mal - Mallinckrodt, Inc.

ERS - E.R. Squibb & Sons, Inc.

Cin - Cintichem, Inc.

Med - Medi-Physics, Inc.

The information which follows on package descriptions was provided via telephone by individuals employed by the various radiopharmaceutical shippers.

Mallinckrodt, Inc.

- Note 1 Liquid enclosed in a septum-top vial; vial surrounded by sponge; vial and sponge placed inside a double-walled plastic container with a screw on cap; plastic container placed in foam insert; insert placed in cardboard box.
- Note 2 Liquid enclosed in a septum-top vial; vial surrounded by sponge; vial and sponge placed inside a lead shield; shield placed inside plastic container with a screw on cap (lead in cap); container placed in foam insert; insert placed in cardboard box.
- Note 3 Liquid enclosed in a sealed vial; vial placed in formed foam container; container placed in cardboard box.
- Note 4 Liquid enclosed in a square shaped septum top vial; vial inside a lead shield bored to fit with screw on cap (sponge in cap); shield placed in foam insert; insert placed in cardboard box.
- Note 5 Capsules enclosed in pop-top plastic bottle; foam material added at top and bottom of bottle; bottle and foam placed inside a lead shield; lead shield placed inside a plastic container with screw on cap; plastic container placed inside foam insert; insert placed in cardboard box.
- Note 6 Gas enclosed in a septum-top vial; vial placed in cylindrical lead shield; vial and shield inserted into plastic sleeve; plastic sleeve placed in formed foam container; container placed in cardboard box.
- Generator $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ column inside pineapple-shaped lead shield approximately 5 in. in diameter; lead shield and saline bottle (~700 ml) encased in form-fitted plastic container in portable-typewriter-case shape (two halves bolted together); elution vials placed in foam insert and placed in storage compartment at top of plastic container; plastic container placed in plastic bag and then into molded foam insert; insert placed in cardboard box.

New England Nuclear Corp.

- Note 1 Liquid enclosed in septum-top vial; vial placed inside a plastic bag; plastic bag placed inside blue plastic tube with snap-on cap and absorbent material in bottom; blue plastic tube placed in a three-slot foam insert; insert placed in telescoping cardboard box.
- Note 2 Liquid enclosed in septum-top vial; vial suspended inside a lead shield with sponge in cap; shield cap taped on (circumferentially); shield placed inside a plastic container with a tamper-proof cap; plastic container placed in a foam cradle; cradle placed in cardboard box.
- Note 3 Gas enclosed in septum-top vial; vial placed in lead tube of varying capacity (up to five vials depending on shipment); tube capped on both ends with lead (one fixed with epoxy--the other with tape in axial direction); tube placed in foam cradle; cradle placed in cardboard box.

Generator $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ column inside double-walled lead shield whose external form is cylindrical; lead shield encased in form-fitted high-impact plastic container; plastic container placed into molded foam insert along with 20 saline vials and 20 empty vials (each in individual wells); insert placed in cardboard box.

E.R. Squibb & Sons, Inc.

Note 1 Capsules enclosed in plastic bottle with screw on cap; plastic bottle placed in lead shield; shield cap taped on (circumferentially); shield placed in thick plastic shrink band; shield and shrink band placed in solid foam block; foam block placed in cardboard box.

Note 2 Liquid placed in screw-cap vial; vial placed in lead shield with sponge material at the top; shield cap taped on (circumferentially); shield placed in thick plastic shrink band; shield and shrink band placed in solid foam block; foam block placed in cardboard box.

Note 3 Liquid placed in septum-top vial; vial placed in lead shield with sponge material at the top; shield cap taped on (circumferentially); shield placed in thick plastic shrink band; shield and shrink band placed in solid foam block; foam block placed in cardboard box.

Generator $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ column inside lead shield that is essentially cylindrical in shape; lead shield in polypropylene plastic bucket with a snap-on polypropylene top; plastic container placed into molded foam insert along with ten elution vials, ten evacuated vials, one paraben vial, and one adapter assembly; insert placed in cardboard box.

Medi-Physics, Inc.

Note 1 Gas enclosed in septum-top vial; vial wrapped with absorbent material (paper like); vial and absorbent material placed in lead shield; lead shield placed in a tamper-proof plastic container (lead in cap); plastic container fitted into cardboard suspension insert; cardboard suspension insert placed in cardboard box.

Note 2 Liquid enclosed in septum-top vial; vial wrapped with absorbent material (paper-like); vial and absorbent material placed in lead shield; lead shield placed in a tamper-proof plastic container (lead in cap); plastic container fitted into cardboard suspension insert; cardboard suspension insert placed in cardboard box.

Cintichem, Inc.

Generator $^{99}\text{Mo}/^{99\text{m}}\text{Tc}$ column inside oval-shaped lead shield; lead shield encased in form-fitted polystyrene container (top and bottom halves bolted together); ten elution vials (10 cm^3 each) placed in foam insert and placed in storage compartment at top of plastic container; plastic container placed into molded foam insert; insert placed in cardboard box.

DAMAGE SUSTAINED BY PACKAGES

According to inventory records prepared from notes taken at Mallinckrodt facilities in Saint Louis two days after the accident, 30 of the 76 packages containing radiopharmaceuticals were damaged to the extent that their outer packaging was destroyed, and the balance had their outer packaging intact. Table 3 presents a summary of the package damage. Figures 10, 11, and 12 present graphic illustrations of the state of damage of the packages. In the context of this report, a package whose packaging was destroyed is one whose outer Type A container (cardboard box and shock-absorbent material) is no longer capable of containing the radioactive-material containment vessel and lead shield. This would include a radioactive-material containment vessel lying by itself on the road or a package where the radioactive-material containment vessel, even though still within the confines of the outer package, could fall out if the orientation were altered. Conversely, an intact package is one whose outer Type A container suffered slight or no damage and whose radioactive-material containment vessel was in its original packing configuration.

Twenty-five of the 30 radioactive material sources whose outer packaging was destroyed had intact containment vessels and shielding, three had intact containment vessels but were unshielded, and two had broken containment vessels and were unshielded. Seventeen of these 30 packages contained ^{99m}Tc generators, or nearly 52% of the total generators present (Figs. 13 and 14). Furthermore, when a comparison is made for each shipper of the ratio of surviving generator packaging to total generators shipped, the following results are obtained: 10/12 for Mallinckrodt, 5/8 for New England Nuclear, 0/7 for Squibb, and 1/1 for Cintichem. When the five used Mallinckrodt generators are included, Mallinckrodt's ratio of surviving generator packaging to total generators present becomes 10/17. However, note must be made of the fact that the quality of repackaging for the five used generators is unknown.

Table 3. Summary of package damage in the accident near Brookhaven, Mississippi on December 3, 1983.

Shipper	Nuclide	Preaccident package condition ^a
<u>Containment vessel intact and shielded--packaging destroyed</u>		
Mallinckrodt, Inc.	⁹⁹ Mo	Mallinckrodt generator
	⁹⁹ Mo	Mallinckrodt generator ^b
	⁹⁹ Mo	Mallinckrodt generator ^b
	⁹⁹ Mo	Mallinckrodt generator ^b
	⁹⁹ Mo	Mallinckrodt generator ^b
	⁹⁹ Mo	Mallinckrodt generator ^b
	¹³¹ I	Mallinckrodt note 4
	¹³¹ I	Mallinckrodt note 4
	¹³¹ I	Mallinckrodt note 2
	¹³¹ I	Mallinckrodt note 5
	¹³³ Xe	Mallinckrodt note 6
New England Nuclear Corp.	⁶⁷ Ga	New England Nuclear note 1
	⁹⁹ Mo	New England Nuclear generator
	⁹⁹ Mo	New England Nuclear generator
	⁹⁹ Mo	New England Nuclear generator
	¹³³ Xe	New England Nuclear note 2
	¹³⁷ Cs	New England Nuclear note 2 ^c
E.R. Squibb & Sons, Inc.	⁹⁹ Mo	Squibb generator
	⁹⁹ Mo	Squibb generator
	⁹⁹ Mo	Squibb generator
	⁹⁹ Mo	Squibb generator
	⁹⁹ Mo	Squibb generator
	⁹⁹ Mo	Squibb generator
	¹³¹ I	Squibb note 3
Medi-Physics, Inc.	¹³³ Xe	Medi-Physics note 1
Subtotal	25	

Table 3. (Continued.)

Shipper	Nuclide	Preaccident package condition
<u>Containment vessel intact and unshielded--packaging destroyed</u>		
Mallinckrodt, Inc.	^{99}Mo	Mallinckrodt generator
E.R. Squibb & Sons, Inc.	^{99}Mo	Squibb generator
	^{131}I	Squibb note 2
Subtotal	3	
<u>Containment vessel broken and unshielded--packaging destroyed</u>		
Mallinckrodt, Inc.	^{131}I	Mallinckrodt note 2
New England Nuclear Corp.	^{67}Ga	New England Nuclear note 1
Subtotal	2	
Grand Total	30	

^a The notes referred to in this column are after Table 2.

^b Depleted return. Quality of repackaging unknown.

^c Limited-quantity shipment.

Figure 10. Illustration of a damaged outer package with radioactive-material containment vessel intact and shielded.

Figure 11. Illustration of a damaged outer package with radioactive-material containment vessel intact and unshielded.

Figure 12. Illustration of a damaged outer package with radioactive-material containment vessel broken and unshielded.

Figure 13. ^{99m}Tc generator shield stripped free of all external packaging, at the side of the road near Brookhaven, Mississippi on December 3, 1983.

Figure 14. ^{99m}Tc generator shields and plastic container recovered from the accident scene near Brookhaven, Mississippi. Photograph taken in Saint Louis, Missouri on December 11, 1983.

RADIOACTIVE MATERIALS RELEASED

As a result of the accident, two packages failed to the extent that their primary containment was breached, resulting in contamination of the local environment.

A New England Nuclear package consigned to West Jefferson General Hospital, Marrero, Louisiana, waybill number 8348-3-F-048, contained two packages of liquid ^{67}Ga within a two-package foam cradle within a cardboard box. The two packages of liquid ^{67}Ga in septum-top vials (see New England Nuclear note 2 after Table 2) had bills of lading activities of 0.006 Ci and 0.089 Ci (calibration time 2 Dec. 1983). At the time of the accident, the vial of liquid ^{67}Ga at 0.006 Ci (calculated activity of 0.00468 Ci at 4 p.m. CST, 3 Dec. 1983) was ejected from its lead shield and subsequently broke. Vial remnants were found within the confines of its damaged outer package (Fig. 15), and there was local contamination of the highway. Since it cannot be determined to what extent the package materials may have absorbed some of the liquid ^{67}Ga , it is assumed that all activity in the vial was released to the local environment.

The second package, shipped by Mallinckrodt and consigned to Jo-Ellen Smith Hospital, New Orleans, Louisiana, invoice number J793028, contained a total of six packages within a six-package foam insert within a cardboard box. There were five packages of liquid ^{131}I in septum-top vials (see Mallinckrodt note 2 after Table 2) at 0.001 Ci each (calibration time 12 p.m. CST, 9 Dec. 1983) and one package of encapsulated liquid ^{131}I in a pop-top plastic bottle (see Mallinckrodt note 5) at 0.00075 Ci (calibration time 12 p.m. CST, 5 Dec. 1983). As a result of the accident, one vial of liquid ^{131}I (calculated activity of 0.00165 Ci at 4 p.m. CST, 3 Dec. 1983) was ejected from its lead shield and consequently broke. The vial was obliterated and there was no evidence of its package nearby. All activity was assumed to be released to the local environment.

Figure 15. Damaged package containing a ^{67}Ga source that contaminated the local environment near Brookhaven, Mississippi on December 3, 1983.

MECHANICAL ANALYSIS

Design Standards and Regulations

The packaging and transport of medical radiopharmaceuticals are governed by Department of Transportation (DOT) regulations Title 49, Chapter I, Section 173.4. Packages intended to meet these requirements are designed by various suppliers of radiopharmaceuticals and take many forms. Type A packages must be qualified by test in accordance with subsection 173.465, and if the containment has liquids or gas, subsection 173.466. In brief, these regulations require that the packaging demonstrate resistance to impact (by dropping), to crush, and to penetration after having been exposed to simulated rainfall for one hour. In addition, radiation shielding, when provided, must prevent "unintentional escape" of portions of the containment system. If the radioactive material is in liquid form, then absorbent material or secondary containment must be provided to "assure retention of liquid."

In the analysis, we found it appropriate to divide the containment systems and packaging into two categories: one which contains small vessels capable of easy removal from their packaging, and another, typical of the Mo/Tc generators, which contains vessels intended to be used in place. The varieties of packaging systems are described in the notes after Table 2. Both instances of release of radioactive material in the subject accident involved packages of the first kind. The sole "failure" of a (generator) package of the second kind was limited to the release of the primary containment with its integral shield and did not result in contamination (Figs. 16 and 17).

Analysis of Packaging for Removable Radioactive-Material Containment Vessels

With the exception of generators, packaging designs consist of a lead shield within which the radioactive-material containment vessel is enclosed. Surrounding the lead shield is load-mitigating and shock-attenuating material intended to meet the impact, crush, and penetration requirements of the regulations. In all designs encountered in this investigation, this mitigating material consisted of preformed plastic foam shells retained by a surrounding fiberboard carton; the protection depended almost entirely on the compressive strength of the foam. Three generic forms of packaging used by each of the suppliers are shown in Figs. 18, 19, and 20.

Each of the designs appears to meet the letter of the regulations—so long as the enclosing fiberboard carton remains intact. Of the 76 packages containing radiopharmaceuticals exposed to the accident, 30 had their outer packaging damaged, rendering it useless. In some instances, damage consisted of destruction of the fiberboard carton followed by the separation of the foam enclosures. Many of these foam protectors were ground into small debris as a result of the accident.

Provision for restraint of the radioactive-material containment vessel and for closure of the lead shield vary considerably among the designs. The designs illustrated in Figs. 18 and 20 rely on a simple step joint and adhesive tape or shrink-film wrap to secure the two parts of the lead shield. The third employs a close-fitting molded polymer jacket with integral screw threads to make the closure. None make effective provision to assure retention of the radioactive-material containment vessel within the lead shield as required by 173.412(k) or to assure retention of the absorbing material about the radioactive-material containment vessel should the lead shield be breached. While the presence of adsorbent material about the containment vessel meets the literal requirement of 173.412(n)(2), the design is such that the absorbent material is associated

Figure 16. Inner lead shield for the $^{99\text{m}}\text{Tc}$ generator in the eastbound lane of the accident scene near Brookhaven, Mississippi on December 3, 1983.

Figure 17. Outer lead shield for the $^{99\text{m}}\text{Tc}$ generator in a ditch near the westbound lane of the accident scene near Brookhaven, Mississippi on December 3, 1983.

Figure 18. Cross-section of a generic radioactive-material containment vessel and lead shield used by New England Nuclear Corp.

with the lead shielding and "not suitably positioned to assure contact with the liquid" should the lead shielding separate. Consequently, since the absorbent is associated with the lead shielding, it does not provide the protection intended by 173.412(n)(2). This appears to be contrary to the design requirements of subsection 173.412. In addition, provisions for attenuation of secondary impact of the containment vessel, usually made of glass, with the lead shield are rudimentary at best or nonexistent. Our analysis shows that this secondary impact may well result in fracture of the containment vessel even when the lead shield remains intact.

Integrity of the Lead Shield

Our most consistent observation was the failure of the closures used with the lead shield once the restraint of the shock-absorbing material had been lost. These lead shields (Figs. 18, 19, and 20) vary in weight from a little more than 1 to nearly 10 lb. Except for the Mallinckrodt design (Fig. 19), they were sealed with (vinyl) adhesive tape or (acetate) shrink wrap capable of little more than restraining their own weight (< 50 g). The

Figure 19. Cross-section of a generic radioactive-material containment vessel and lead shield used by Mallinckrodt, Inc.

Mallinckrodt design, the smallest and lightest of the group, employs a flexible plastic overjacket containing integral (hose-type) threads between the body and lid. We estimate the unrestrained strength of the latter closure to be of the order of 250 to 300 times the weight of the container, i.e., 250 to 300 g. We feel that the resistance to separation (integrity) of the former two tape- and wrap-sealed designs after release under highway crash-dynamic conditions (up to 1000 g), such as experienced in this accident, is trivial.¹ The threaded enclosure appears to be better but still falls short of the capability to withstand the specific magnitude of expected dynamic conditions.

Container integrity is not the only issue, however, in the design of the lead shield. Shielding, protection against impact and ultimate containment or absorption of released radioactive contents are others. Fortunately, the selection of lead for its shielding properties carries with it a benefit of relatively benign response to impulse. Its transmission of dynamic stress (acoustic impedance) is low and attenuation high, so the design of survivable enclosures should be straightforward.²

None of the lead shield designs surveyed appeared to attempt liquid-tight closure, although the Mallinckrodt design comes close. All include some form of absorbent in the

Figure 20. Cross-section of a generic radioactive-material containment vessel and lead shield used by E.R. Squibb & Sons, Inc.

cavity, but surprisingly, none provide effective measures to assure that the liquid is absorbed. An obvious possibility would seem to be that an absorbent material be precompressed to a stiffness appropriate to shock absorption of the containment vessel and surround it completely.

Impact Loading of the Radioactive-Material Containment Vessel

Impact is the rapid application of load, either by an external agent (with or without restraint of resultant acceleration), or conversely, the sudden impediment to motion, resulting in inherent inertial loads. Rapid loading implies loading times short with respect to the natural periods of deformation of the body. Bodies in free flight or free fall experience loads on arrest or deceleration generally proportional to the rate of deceleration. In the simplest example, a body in motion which is brought to rest by a

uniform medium experiences a decelerating force proportional to the resistance of the medium over a distance which depends on its initial energy (velocity). Thus, a body of weight W, dropped a distance D, which is brought to rest in a distance d by a uniform medium (Fig. 21) will experience a peak force n times its own weight.³

$$n = \frac{2(D + d)}{d}$$

and the factor of 2 accounts for the dynamic impulse of sudden loading.

As applied to the issue of packaging of radiopharmaceuticals, the shock-absorbing material is sized such that decelerations from expected impact velocities can be accomplished within the available thickness of the absorber without exceeding acceptable deceleration stresses in the containment system. Where the regulations require survival of a drop from 30 feet, outer packaging thickness of the order of 1/3 foot can produce decelerations of about 180 times that of gravity ("g"). We need to recall, however, that in the case of the packaged pharmaceutical vial, the dominant element (mass) of the system is the lead shield, and it is in effect this lead shield which is being protected. The radioactive-material containment vessel simply goes along for the ride and when the lead shield stops, it too must stop. If the radioactive-material containment vessel is unprotected from the rigid lead shield, the test of its survival is the ultimate impact between it and the lead shield.

Response of A Radioactive-Material Containment Vessel to Impact

Using a simple cylindrical model for the radioactive-material containment vessel, an estimate can be made for the stresses which result from impulsive acceleration or arrest, and ultimately, those which will result in failure.

An ideal cylinder of an elastic material--such as glass--will make contact with a uniform surrounding body (the lead shield) along an axial line. Under a normal gravitational field, the force between the enclosure and the cylinder is simply the "weight" of the cylinder distributed over the length of the line contact. This force results in stresses within the cylinder which are a maximum in tension in the wall opposite the point of contact. An approximate solution for the resulting stress $\sigma_{\max}$ is given by Roark.⁴ For the proportions shown in the accompanying illustration (Fig. 22), that resulting stress is approximately

$$\sigma_{\max} \approx 22 n R \text{ psi.}$$

where n is the magnitude of acceleration or deceleration in g, R is the radius of the cylinder in inches, and t is the wall thickness. In this example, $t = R/10$.

If for example we measure the strength of a 1 inch diameter glass containment vessel of these proportions to be 10,000 psi, we would predict that an impact registering approximately 900 g would be required to produce fracture.

Carrying our example one step further, if a glass containment vessel were traveling 70 mph (102 ft/s) and came to rest in 0.18 ft (2.18 in.), the resulting deceleration would be approximately 900 g, which is in the range of the likely maximum velocities and stopping distances experienced by parcels in the present accident--providing the attenuating media remained intact. In the present example, survival of the glass containment vessel is as much determined by secondary impact with the lead shield as by uniform arrest of the lead shield itself. Even a small unmitigated clearance between the glass containment vessel and lead shield can result in substantial disparity in the peak impulse between the two.

Figure 21. Deceleration of a body by uniform deformation.

Figure 22. Illustration of stress in a cylinder under direct bearing.

Analysis of Packages with Integral Containment: Generators

All three of the generator designs represented in the lot involved in the accident provide some restraint for the containment vessel within the lead shielding. Of these, only one, the Squibb design (Fig. 23), released its inner lead shield with containment vessel under the impact conditions of the accident. This inner lead shield, although without provision for impact attenuation, appeared to provide adequate protection to the containment vessel such that no rupture or release resulted. In the Squibb design, the inner lead shield is secured by a polypropylene shear pin. While it is presumed that the pin securing the source in question did fail, it was not recovered for examination. Based on the methodology of the previous section and the assumed properties of the unrecovered pin, we would estimate the retention section capability of the design to be no more than

Figure 23. Cross-section of the E.R. Squibb and Sons, Inc. ^{99m}Tc generator.

250 g, probably appreciably less than that of the containment vessel itself. An alternate possibility remains that the specific material used in the securing pin of this article was substandard or substituted.

Analysis of Vehicle Damage

Three vehicles were involved in the accident. Of these, only the Fruehauf luggage trailer is believed to have substantially affected the consequences of the accident. Not only was the trailer totally destroyed in the accident but the course of destruction included the failure of its primary structural members--the frame and the drawbar--which contributed substantially to the outcome.

The basic specifications for the trailer are shown in the following table. Its appearance is shown in Figs. 1 and 2.

Table 4. Specifications of the Fruehauf Trailer

Manufacturer	Fruehauf Corp., Detroit, Mich.
Model	UA 5.5-8.5-K1
Serial	F28470
Net weight	880 lb
Design G.V.W.	2000 lb
Actual cargo wt.	1315 to 1405 lb (this report)
Actual G.V.W. (est.)	2195 to 2285 lb

This luggage trailer is a single-axle, light-duty, general-purpose vehicle with a useful load capacity slightly in excess of 1/2 ton (1120 lb). As constructed, it is equipped with a lightweight integral aluminum cover, panel rear doors, a sheet metal coupler, and light-duty 13-inch-rim wheels, probably intended to be equipped with "B" section (1220 lb load rating) tires. The tires and wheels of the trailer involved in the accident had been replaced by the operator with larger sizes. The hitch showed evidence of repeated repair by welding.

The unusual aspect of the design of the trailer is the absence of any substantial direct structural connection between the drawbar ("A" frame) and the running gear (axle and spring perches). The sole continuous member is a light extruded aluminum perimeter channel (Fig. 24). On initial impact, the front of the Oldsmobile appears to have driven the trailer ahead against the Carryall, deforming its hitch, rear bumper, and the lower portion of the rear panel doors. It then overrode the trailer platform, demolishing the superstructure (cover), ejecting the cargo, crushing the right wheel, and crushing the axle to the ground. (Note: the weight of the Oldsmobile at the time of the accident was probably about 5300 lb.) The increased resistance (drag) of the crippled trailer likely caused the inertia of the Carryall to exert a drawbar traction on the trailer, which failed its plywood platforms and perimeter channel, allowing the entire front of the trailer to separate and remain attached to the Carryall. The remainder of the trailer, now only a plywood deck and axle, was crushed beneath the Oldsmobile, which apparently spun through 180 degrees with the trailer as a pivot. The entire cargo had been strewn along behind.

Figure 24. Structural outline of the trailer, showing a lack of attachment between the drawbar and axle.

Because of uncertainties in the compliance (flexibility) of the trailer frame and two-hitch combination, it is impossible to make reasonable estimates of the load conditions which the vehicles experienced. The speed estimates of the Highway Patrol report, 70 mph for the Oldsmobile and 50 to 55 for the Carryall, appear reasonable. The speed of the packages when ejected from the trailer would likely have been between these two values.

The Carryall and Oldsmobile were roughly comparable in weight: 6000 and 5300 lb, respectively. The forward deformation of the bumper, hitch, and doors of the Carryall on initial impact confirm the excess speed of the Oldsmobile compared with that of the Carryall. The complete demolition of the trailer would tend to emphasize this difference of speed (and energy) if it were not for the relative lack of damage to the Oldsmobile and the gross structural deficiency of the trailer.

CONCLUSIONS

In reviewing the response of the carrier and Mississippi State and local authorities to the accident, it can be concluded that procedures for reporting, assessing contamination, and cleanup of the site were effective in minimizing the impact of the accident upon the local environment.

While it is recognized that Type A packages are not required to maintain their integrity under severe accident loadings, it appears that some simple inexpensive measures could be taken to reduce the possibility of radioactive release. If lead shields are to be secured with tape or shrink bands, it would be more effective if a fiberglass-reinforced tape were used and wrapped in an axial rather than circumferential direction. It is also suggested that additional packing material be added to prevent impact of the glass vials on the side of the lead shield and to more effectively absorb radioactive liquids in the event of containment vessel fractures. Furthermore, it is suggested that a metal pin replace the polypropylene shear pin on the Squibb design to maintain the integrity of the lead shielding.

The practice of recording the calibration level of activity on the bill of lading instead of the maximum activity at any time during transportation appears to be in violation of 49 CFR 172.203(d)(iii).

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13. ABSTRACT (200 words or less) <p>A rear-end collision occurred between a passenger automobile and a luggage trailer carrying 84 packages, 76 of which contained radiopharmaceuticals, on U.S. Highway 84 near Brookhaven, Mississippi on the afternoon of December 3, 1983. The purpose of this report is to document the mechanical circumstances of the accident, confirm the nature and quantity of radioactive materials involved, and assess the nature of the physical environment to which the packages were exposed and the response of the packages. The report consists of three major sections. The first deals with the nature and circumstances of the accident and findings of fact. The second gives an accounting and description of the materials involved and the consequences of their exposure. The third gives an assessment and analysis of the mechanisms of damage and the conclusions which may be drawn from the investigation.</p>			
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