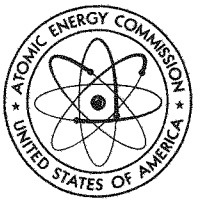
TID-7651

Summary Report of AEC Symposium on Packaging and Regulatory Standards for Shipping Radioactive Material

held in

Germantown, Maryland

December 3-5, 1962



UNITED STATES ATOMIC ENERGY COMMISSION
Division of Technical Information Extension

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TID-7651

HEALTH AND SAFETY

Summary Report of AEC Symposium on Packaging and Regulatory Standards for Shipping Radioactive Material

held in

Germantown, Maryland

December 3-5, 1962

Sponsored by

Divisions of Licensing and Regulation
Operational Safety
and
Reactor Development
U. S. Atomic Energy Commission

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PREFACE

It was the purpose of this Symposium to bring together those who have performed tests on radioactive material shipping containers and those who are responsible for approving containers for shipping radioactive material. The discussion of the relationship between these areas was intended to promote understanding of container design requirements by all and to provide guidance for future testing programs. The sponsors believe this forum served its primary purpose and proved to be a most useful means of bringing together the information available on container testing and evaluation.

We who were present at the Symposium and those who find the information in the report of the Symposium useful are indebted to all who prepared papers or participated in any way. Although no names are attached to the comments in this report, the sponsors were pleased that nearly every person present participated in some portion of the discussion.

OPENING SESSION

MONDAY AFTERNOON - DECEMBER 3, 1962

INTRODUCTION AND WELCOME

The AEC Symposium on Packaging and Regulatory Standards for Shipping Radioactive Materials convened in the Headquarters Auditorium of the U. S. Atomic Energy Commission, Germantown, Maryland, at one o'clock, Lester R. Rogers, Division of Licensing and Regulation, Symposium Chairman.

Symposium Chairman: Gentlemen, on behalf of the sponsoring divisions, the Divisions of Operational Safety, Reactor Development and Licensing and Regulation of the Atomic Energy Commission, I wish to welcome you to the Symposium on Packaging and Regulatory Standards for Shipping Radioactive Materials.

We are glad to see such a good representation from the AEC Operations Offices and Contract Activities. We extend a very special welcome to our guests from other countries.

The subject which we will discuss for the next 2-1/2 days is of great importance and of interest both to the Atomic Energy Commission and the Atomic Energy industries. The need for transportation of radioactive fuels and isotopes throughout the U. S. and throughout the world is inherent in a growing atomic energy industry. The provisions which are made to protect public health and safety in the movement of these materials are of particular concern to the shipper, the Federal, State and local groups. It is essential that standards of testing to implement the standards be developed.

It is also very essential that the Federal, State and local regulatory agencies work together to understand the problems of transportation and, to the extent possible, attain compatibility of packaging standards and transport regulations so that material can move freely and safely throughout the U. S.

Interchange of information in this area between the various countries is also important to the development of regulations governing the international transport of radioactive materials. The regulations published in May 1961, by the International Atomic Energy Agency established a basis for compatibility of national and international regulations.

A great deal of work on transportation regulations has been done in other countries. A Symposium was held by the United Kingdom at Bournemouth, England during the week of October 8 through 10th, 1962. Four U. S. representatives attended that Symposium and found it to be very informative.

Present today are representatives from the UK and Canada who will present papers later in this Symposium.

Through this meeting we hope that all of us may become better informed as to the safety testing programs on shipping containers and status of development

of regulations dealing with the safe transport of radioactive materials and some of the problems.

I turn the meeting over to Dr. Nathan Woodruff, Chairman of this Session.

SESSION I - THE TRANSPORT ENVIRONMENT

Chairman:

I would like to introduce Mr. Patterson of the Division of Operational Safety.

TYPES AND QUANTITIES OF MATERIALS BEING SHIPPED AND AEC ACCIDENT EXPERIENCE

by

D. E. Patterson
Division of Operational Safety
U. S. Atomic Energy Commission

INTRODUCTION

This paper includes two reports, "Summary of Shipments of Radioactive Materials for Six Month Period, October 1, 1961 through March 31, 1962" and "A Summary of Incidents Involving AEC shipments of Radioactive Material 1957 - 1961."[1/] While these reports were not originally intended to be complimentary, it was recognized that knowledge of current shipping experience when related to the accident experience might indicate an accident frequency rate for the transportation of radioactive materials.

In the shipping experience report, a shipping rate for both AEC and AEC licensees was developed. However, the incident summary contains only those incidents which occurred to AEC shipments. Additionally, some of the incidents were not public transportation type of incidents but occurred during on-site movement of radioactive materials. Therefore, in determining the accident frequency, it has been necessary to extract the AEC's shipping experience and compare it only with off-site AEC accidents for comparable periods.

The incident summary provides information pertaining to the performance of packages under accident conditions. In the second part of this paper an analysis is made of container performance. For this purpose it does not matter where the accident took place, so both off-site and on-site accidents have been included in the study.

It is hoped that the actual experience can be of value in developing regulations which assure safety during transportation. While some points along these lines have been explored, it is important to note that the shipping experience is still statistically small, and we may just not have encountered the type of accident which we want to prevent. On the other hand, since the number of shipments is relatively small, it may be possible to accept some higher probability of accident knowing that the exposure is limited and the chance that an indi-

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1/ The report "Summary of Shipments of Radioactive Materials for Six Month Period, October 1, 1961 through March 31, 1962," is included as part of this paper. "A Summary of Incidents Involving AEC Shipments of Radioactive Material, 1957 - 1961," has been issued as TID 16764 and is, therefore, not included in this document.

vidual accident will occur is reasonably small. This, of course, must be evaluated in the light of the potential loss which might result from such an accident.

AEC Accident Frequency Rate

In analyzing the AEC's current shipment experience, it is found that for the six month period covered by the survey, 23,346 shipments were made. Converting this to an annual rate, it appears that the AEC's current shipping rate is approximately 47,000 shipments per year.

During the five year period covered by the incident summary, it was found that a total of 47 accidents occurred. However, six of these were on-site accidents, and must be eliminated for purposes of establishing a frequency rate. Therefore, we find that for the five year period there were 41 accidents or an average of 8.2 per year.

Comparing 8.2 accidents per year with the shipping experience of 47,000 shipments per year, we find that the accident frequency rate is .17 accidents per thousand shipments. Because many of these shipments move by commercial channels, it would be extremely difficult to obtain records of the actual mileage traveled. If we estimate that an average shipment travels between 100 and 1,000 miles, we can then determine an order of magnitude for shipping frequency based on miles of exposure. These figures come out to be 1.7 and .17 accidents per million miles.

As you will see from Dr. Leimkuhler's report, this is slightly less than all truck accidents. It is believed that AEC shipments of radioactive materials are suffering accidents at a frequency somewhat below the average frequency for all commodities.

If we consider only those off-site accidents where the package was breached, we find 15 such cases during the five year period, or three per year. Following the same reasoning as above, a range of .64 to .06 accidents, causing the breaching of the container, per million miles is obtained.

Analysis of Packages Involved in Accidents

The IAEA regulations, and the new regulations proposed for use in the U. S., have adopted the principle that certain small quantities of radioactive material can be packaged in an ordinary or "Type A" package, since the release of this material in an accident would not present undue risk of exposure to personnel. Quantities above these must be packaged in a high quality or "Type B" package, which is designed to survive a credible accident. Keeping this in mind, an analysis was made of the 47 accidents, looking particularly at those involving severe accidents and those where the container failed. It might be presumed that there would be a relationship between severe accidents and container failures. However, it was found that this is not the case. While there have been a number of severe accidents, only a few containers failed as a result of these. It was found that the bulk of container failures were due to reasons other than severe accidents.

Analysis of Severe Accidents

It was found that there were 15 accidents which can be considered as severe impact type transportation accidents. Additionally, there were two serious fires. It should be pointed out that while these were serious accidents, they

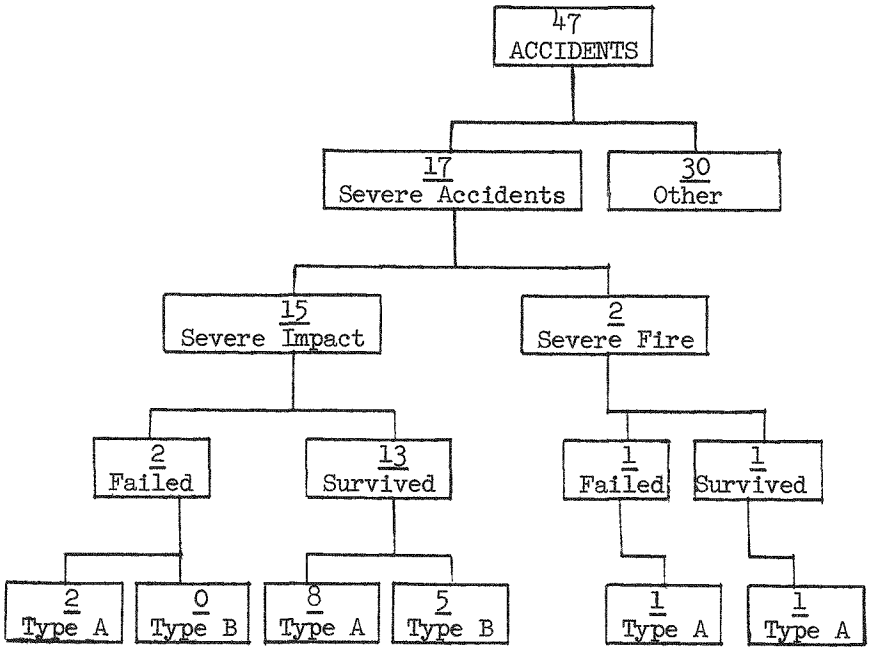
did not involve complete destruction of the vehicle and might not be considered a "maximum" credible accident.

Of the 15 severe impact type accidents, only two resulted in a failure of the container. These were packaged in what would be considered to be "Type A" packages. One was the failure of a fiberboard box. The other was the failure of wooden boxes carrying normal uranium slugs.

Of the two serious fires, one resulted in failure of the container. In fact, in this case the fire originated within the container due to spontaneous ignition of uranium chips. Again, the container that failed would be considered as a "Type A" container.

On close review of the 13 cases involving severe impact but no failure of the container, it was found that five of these would be similar to "Type B" packages and the remaining eight would be "Type A" packages. However, it should be noted that of the eight "Type A" packages, six were large steel shipping containers designed particularly for shipping bulk quantities of uranium oxide or uranium hexafluoride. Because of the density of these materials, the six containers were undoubtedly built more ruggedly than the normal "Type A" container. The five "Type B" cases all involved irradiated fuel element shipments. While the container was not designed specifically to the currently proposed criteria for a "Type B" package, it is apparent that the designs now used incorporate sufficient ruggedness to withstand a certain degree of accident. It is also apparent from these cases, that the vehicle absorbed much of the impact energy.

An overall analysis of the severe accident situation is shown in the following simplified line diagram.



ANALYSIS OF SEVERE ACCIDENTS

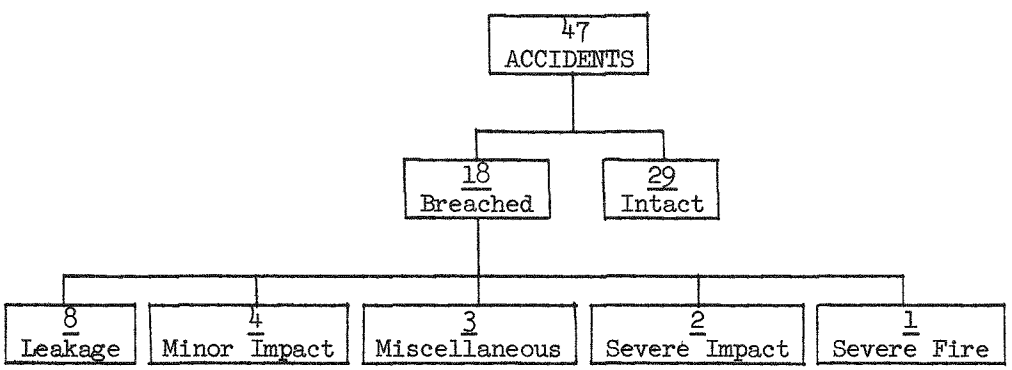
Figure 1

Analysis of Breached Containers

Looking at the 18 cases where the container was breached, it is noted that two failures occurred as a result of severe impact accidents, and one failed in a severe fire. Four other cases, in this group, failed because of the unique characteristics of a "Type A" package, particularly those containers which are light weight and subject to crushing or breaking as a result of relatively normal transportation impacts. For example, several packages were dropped at terminals and run over by vehicles. Obviously, a large lead and steel container would not suffer the same fate. In one case a wooden box broke somewhere in transit. It is not clear whether this was during normal conditions of transit or whether it had suffered an accident along the way.

It became readily apparent, in reviewing these cases, that one type of situation stood out from all others. This was the leakage of liquid from a container. Leakage accounted for eight of the 18 container failures, and was almost exclusively, the mechanism by which radioactivity was dispersed beyond the confines of the container.

The following line diagram shows the overall analysis of accidents in which the container was breached.



ANALYSIS OF BREACHED CONTAINERS

Figure 2

Summary

In light of the AEC accident experience for the five year period, 1957 - 1961, and the current shipping experience, it can be stated that:

1. the current frequency rate for all AEC accidents probably ranges between 1.7 and .17 accidents per million miles;

2. the current frequency rate for containers which are breached ranges between .64 and .06 accidents per million miles;

3. there was no accident which could be described as a "maximum credible accident";

4. 15 severe impact accidents and two severe fires were encountered. Of these the containers were breached in only two of the impact cases and one fire;

5. large containers for irradiated fuel elements encountered severe accidents but did not fail as a result of the severe accident;

6. the 18 cases where the container was breached resulted from the following causes:

a.	leakage of liquid	8
b.	minor accidents unique to "Type A"	4
c.	miscellaneous	3
d.	severe impact accident	2
e.	severe fire	1

SUMMARY OF SHIPMENTS OF RADIOACTIVE MATERIALS FOR SIX-MONTH PERIOD, OCTOBER 1, 1961 THROUGH MARCH 31, 1962

INTRODUCTION

The Interagency Committee on Transportation of Radioactive Materials, composed of representatives of the Interstate Commerce Commission, Coast Guard, Federal Aviation Agency, Post Office Department, Bureau of Explosives and the Atomic Energy Commission, developed the Technical Standards to be Used as a Basis for Preparation of Regulations for the Safe Transport of Radioactive Materials, dated October 9, 1961 1/. It was deemed desirable by the AEC and the Interagency Committee to relate quantity limitations proposed in the Draft Technical Standards to quantities actually being shipped.

Consequently, during the month of May 1962, the Division of Operational Safety undertook a survey of AEC field offices to gather information pertaining to shipments of radioactive materials, other than nuclear weapons, by the AEC and its contractors, and concurrently, the Division of Licensing and Regulation undertook a similar survey of licensees. The results of these two surveys have been compiled and are presented herein.

The information contained in this report should also be helpful in answering questions raised by the transportation industry, insurance industry and local regulatory agencies regarding the types and quantities of radioactive material which are being shipped.

NUMBER OF SHIPMENTS

A questionnaire was sent to each of the AEC field offices, which in turn, was submitted to individual contractors. Upon receipt of the requested information, the field offices compiled reports which were forwarded to Headquarters. Table I shows field office summary totals.

During the six-month survey period (October 1, 1961 through March 31, 1962), the AEC and its contractors made a total of 23,346 shipments of radioactive materials.

1/ A notice that the document was available from the AEC for review and comment was published in the Federal Register during December 1961 and the document was circulated to Field Offices for comments in November 1961.

A questionnaire was sent to licensees who were considered to make the vast majority of all licensee shipments. The total number of shipments reported by the licensees for the period covered by the questionnaire was 85,607 or approximately four (4) times the total number of shipments reported by the AEC and its contractors.

TABLE I

SHIPMENTS OF RADIOACTIVE MATERIALS
BY AEC OR AEC CONTRACTORS (OCTOBER 1, 1961 - MARCH 31, 1962)

OPERATIONS OFFICES	NUMBER OF SHIPMENTS	PER CENT OF TOTAL SHIPMENTS MADE
Oak Ridge Operations Office	15,994	68.3
Hanford Operations Office	1,882	8.1
Chicago Operations Office	955	4.1
Albuquerque Operations Office	954	4.1
New York Operations Office	949	4.1
Brookhaven Office	529	2.3
Grand Junction Office	514	2.2
San Francisco Operations Office	482	2.1
Pittsburgh Naval Reactors Office	331	1.4
Savannah River Operations Office	279	1.2
Idaho Operations Office	254	1.1
Schenectady Naval Reactors Office	223	1.0
TOTALS	23,346	100.0

PACKAGING REQUIREMENTS

In addition to specifying the total number of shipments made, the questionnaires were designed to determine the effect that the Draft Technical Standards would have on the transportation of radioactive material if the proposed standards were adopted by the various Federal regulatory bodies.

The AEC field offices were therefore asked to ascertain:

a. The number of radioactive material shipments made during the six-month period that would have required a type "A" package; 2/

2/ Type "A" packaging is adequate to prevent loss or dispersal of radioactive contents and to retain shielding efficiency under normal conditions of transport.

b. The number of radioactive material shipments made during the six-month period that would have required a type "B" package; 3/

c. Finally, the number of shipments made during this period which would have exceeded the curie limits as specified in the revised standards and would have required prior approval by the Bureau of Explosives before shipment.

In accordance with the Draft Technical Standards, the curie limits for package types are shown in Table II.

TABLE II

MAXIMUM RADIOACTIVITY IN ANY PACKAGE

Type of Packaging \ Group of the* Radionuclide	I	II	III	Confined** Sources	Tritium and Krypton 85
Exempt	10 μc	100 μc	1 mc		--
A	100 μc	10 mc	2 c	20 c	--
B	20 curies		200 c	2000 c	3000 c

*See International Atomic Energy Agency Safety Series Number 6, "Regulations for the Safe Transport of Radioactive Materials," for the nuclides which fall in radiotoxicity Groups I, II, and III.

**"Confined Source" is any radioactive material, irrespective of the toxicity group to which the material belongs, in a massive solid form or encapsulated or confined, provided that the solid or the material forming the capsule or confinement (1) is such that the radioactive material is not readily dispersible, (2) is nonfriable, (3) has a melting point equal to or greater than 538° C (1,000° F), and (4) at normal temperatures and pressures in chemically stable, nonsoluble in water, and nonreactive with air or water.

The results of the AEC field office survey are presented in Table III. The licensees were requested to relate number of shipments to a detailed breakdown of quantity of radioactive material per shipment. A shipment was so defined as to be synonymous with an individual package. The results of the licensee survey are presented in Table IV.

3/ Type "B" packaging is adequate to prevent loss or dispersal of radioactive materials and to retain shielding efficiency under normal conditions and under severe accident conditions.

TABLE III

NUMBER OF SHIPMENTS BY TYPE PACKAGE REQUIRED
(AEC AND AEC CONTRACTORS)

Field Offices	Shipments Requiring Type A Package	Shipments Requiring Type B Package	Shipments Exceeding Curie Limits for a Type B Package in Technical Standards*		
			up to 5,000c	5,000 to 50,000c	Above 50,000c
Oak Ridge	7,657	8,337	512	6	
Hanford	1,103	779	772	7	2
Chicago	538	143	56		4
Albuquerque	334	581	192	18	
New York	853	26	1	2	
Brookhaven	523	6	3		
Grand Junction	**				
San Francisco	367	125	123	3	
Pittsburgh	232	99	8		5
Savannah River	91	66	22	8	92
Idaho	77	177	9	23	8
Schenectady	103	120	2		2
TOTALS***	11,878	10,459	1,700	67	113
% of Total Shipments	51.0	44.7	7.3	.2	.5

*Refer to Table II for curie limits allowed in a type B package.

**Ships only uranium ore, ore concentrates and ore samples which are exempt from packaging requirements (see Draft Technical Standards, Section 9 & 10 for exempt materials) due to low levels of radioactivity involved.

***These totals do not add up to the grand total of shipments, due to a small percentage (4.3%) of the shipments which are exempt from packaging requirements.

TABLE IV

QUANTITY LIMITATIONS PER SHIPMENT (LICENSEES)

QUANTITIES OF MATERIAL	NUMBER OF SHIPMENTS
Quantity limits not reported	6,640
Less than 10 microcuries	9,190
10 microcuries to 100 microcuries	8,290
100 microcuries to 1 millicurie	24,822
1 millicurie to 10 millicuries	21,790
10 millicuries to 2 curies	13,726
2 curies to 20 curies	415
20 curies to 200 curies	548
200 curies to 2,000 curies	89
2,000 curies to 5,000 curies	85
5,000 curies to 50,000 curies	7
Above 50,000 curies	5
TOTAL	85,607

The licensees, as pointed out earlier, made approximately four times as many shipments as did the AEC and its contractors during the six-month period of the survey. However, reference to Tables III and IV reveals that the AEC and its contractors made the larger percentage of the large radioactive source (high curie levels) shipments.

MODE OF TRANSPORT

The AEC field offices were requested to submit detailed information regarding the mode of transport utilized by their contractors for the shipment of radioactive materials. A summary of this information is presented in Table V.

The licensees were also questioned regarding the modes of transport utilized in their radioactive materials shipments. The reply furnished was "approximate percentage of shipments by mode of transport." Table VI is a tabulation of shipments by mode made by the AEC contractors and the licensees.

TABLE V

MODE OF TRANSPORT UTILIZED FOR SHIPMENT (AEC CONTRACTORS)
(BY FIELD OFFICE)

	OR	HA	CH	AL	NY	BH	GJ	SAN	PNR	SR	ID	SNR	Mode Sub-Total	Total by Mode	Mode % of Total
TRUCK	5,737	46	675	189	87	209	50	305	240	167	157	97		7,959	34.3
Commercial	2,557	46	282	82	67	208	50	66	208	159	28	91	3,844		
Less than Truckload	438	41	226	26	47	207	2	50	176	14	23	88	1,338		
Truckload	2,119	5	56	56	20	1	48	16	32	145	5	3	2,506		
Government	3,180		393	107	20	1		239	32	8	129	6	4,115		
RAIL FREIGHT	1,187	1,705	4	107	3	2	464		28	7	4	9		3,520	15.0
Less than Carload	2			95					1				98		
Carload	1,185	1,705	4	12	2	2	464		27	7	4	9	3,422		
RAILWAY EXPRESS	4,056	127	139	556	312	56		25	38	98	62	112		5,581	24.0
Less than Carload	1,775	60	139	556	312	56		23	38	19	58	112	3,148		
Carload	2,281	67						2		79	4		2,433		
AIR	5,014	4	71	60	277	262		110	25	7	28	5		5,863	25.0
Express	4,454	4	42	44	274	182		41	16		23	5	5,085		
Cargo	560		29	16	3	80		24	9	7	5		733		
Government								45					45		
MAIL					31			10						41	.2
OTHER					226									226	.9
Mode not reported														156	.6

TOTAL SHIPMENTS 23,346

TABLE VI

AEC AND LICENSEE SHIPMENTS BY MODE OF TRANSPORT

MODE	MODE % OF TOTAL SHIPMENTS	
	AEC	Licensee
Truck	34.3%	20%
Rail Freight	15.0%	3%
Rail Express	24.0%	14%
Air	24.0%	58%
Regular Mail	0.2%	2%
Other	1.5%	3%

RADIATION UNITS PER PACKAGE

One radiation unit as defined in ICC Regulations, paragraph 73.414, Radioactive Materials Labels, equals one milliroentgen per hour at one meter for hard gamma radiation or the amount of radiation which has the same effect on film as 1 mr/hr of hard gamma rays of radium filtered by one-half inch of lead.

Table VII presents a breakdown of shipments by radiation units per shipment.

TABLE VII

AEC AND LICENSEE SHIPMENTS
RADIATION UNITS PER PACKAGE

Radiation Units Per Package	AEC		Licensees	
	Number	% of Total	Number	% of Total
0 - .49	15,370	66.0	42,754	50.0
.5 - .99	2,970	12.7	19,053	23.2
1.0 - 1.9	1,346	5.8	12,466	14.5
2.0 - 2.9	943	4.0	3,668	4.4
3.0 - 3.9	488	2.1	452	.5
4.0 - 4.9	369	1.5	193	.2
5.0 - 5.9	324	1.4	866	1.0
6.0 - 6.9	276	1.2	130	.1
7.0 - 7.9	143	.6	99	.1
8.0 - 8.9	120	.5	89	<.1
9.0 - 10.0	144	.6	365	.4
>10	59	.3	41	<.1
Radiation Units Not Reported	794	3.3	4,631	5.5
TOTALS	23,346	100.0	85,607	100.0

SUMMARY

For the period covered, the total number of licensee shipments exceeds the total number of contractor shipments - 85,607 to 23,346. On the other hand, AEC shipments of large radioactive sources outnumber similar licensee shipments. A large number of licensee shipments go by air (licensees 58% - contractors 25%), indicating the large number of low level, radioisotope shipments made by licensees. The AEC and its contractors, due to the larger number of high curie level shipments and greater bulk, utilize to a greater extend land transport (rail freight, truck, rail express); 73.3% for contractors as versus 37% for licensees. Finally, the great amount of attention paid to reducing the radiation hazard to a minimum is reflected in the low radiation units of shipments by both AEC and AEC licensees.

Remarks by Mr. Patterson: In arranging this program we thought it quite appropriate to start off in our talks about safety testing and safety standards with a discussion of the transport environment. I have been working on two documents, one, a summary of AEC's accident experience for the past five years, has just been completed and is included as part of this paper.

In this document I have looked very closely at all the accidents we could possibly find. There are many that most people would not even consider accidents. They were of such a minor nature. However, over the last five years we had 47 such incidents.

I then tried to place them in the scheme of classification which Jimmy Morgan presented in his document and which he will talk about later.

This sets up the classification in accordance with the release of activity. All of our accidents can be fitted into this scheme. There are six categories ranging from no release of material at all to a release of radioactive material to a water supply. This latter case would be considered the worse sort of situation.

In our accident experience, we had accidents which fitted into the first five classes. We have not had any accident in the last five years in which the material went into a stream or some water source. Of the total of 47 accidents, 29 were in the Class I radiation release where no material was released from the container; i.e., the container remained intact.

There were seven in Class II. These are situations where the container was breached, broken up in some manner, but the material did not come out of the container. In seven more cases the material did come out of the container but did not escape from the vehicle.

There were only four cases then where radioactive material came out of the container as a result of the accident and went beyond the confines of the vehicle. These are described in detail in TID-16764.

In the second report we were trying to learn more about the actual type of materials and the number of shipments that are being made in the United States. This report covered both the AEC's own operations and the licensee's operations Interestingly enough, we found that as far as numbers go, the AEC is now a minority shipper. The licensees of AEC make four times as many shipments per year as does the Atomic Energy Commission.

The AEC is currently shipping about 47,000 packages per year. This is an annual rate. Licensees are shipping about 170,000 articles per year.

The AEC shipments however, represent the large quantities and the AEC uses rail freight, railway express, and truck transportation to the largest extent while the licensees ship the majority of their material by air.

This is a further indication of the large quantities of small radioisotope shipments.

While we have these two documents as part of this paper, in preparing specifically for this meeting we determined the accident frequency rate related to AEC's shipments. I found 1.7 accidents per thousand shipments as our current experience.

Now, normally, an accident frequency is expressed in terms of millions of miles traveled. We had a great deal of difficulty determining the actual mileage

that these shipments traveled during the course of movement. However, in considering the distances involved in the United States and typical shipments, it seems fair to assume that an average shipment moves somewhere between 100 and 1,000 miles during the course of its travels. If we apply these figures we get 1.7 to 0.17 accidents per million miles or in the range of about one accident per million miles of vehicle travel.

This is an order of magnitude and was a little bit lower than Dr. Leimkuhler indicates in his study. Also, the accident frequency rate for those accidents where the container was breached, where there was a failure of the container, ranges from .64 to .06 accidents per mile.

As to the performance of containers under accident situations, I looked at the containers that were involved in severe accidents. However, some of the accidents are very minor in nature, and others are of this severe type but none quite the "maximum credible accident".

During the past five years -- I did not see any accident that occurred to the material being shipped which might be described as the "maximum credible accident". This is a matter of viewpoint. We had one truck shipment where the truck ran into a passenger vehicle. The passenger vehicle was completely demolished and the driver was killed. To him this was a maximum credible accident. However, our truck was hardly damaged. So to our truck it was perhaps not the maximum credible accident.

So, in summing up then, on analyzing the accident experience and our actual shipping experience, I find that we have an accident frequency rate for the AEC of probably somewhere between .17 and 1.7 accidents per million miles of travel.

The frequency rate for containers that are breached ranges between .06 and .64 accident per million miles. There was no accident during this five-year period which could be described as a maximum credible accident.

Of the 15 severe impact accidents, two severe fires were encountered; only two of the containers was breached due to severe impact and only one container was breached due to severe fire.

The Type "B" packages were large containers for irradiated fuel elements which encountered severe accidents but none failed during this five-year period.

The 18 cases where the container was breached resulted from the following causes: leakage of liquid, eight cases. Minor accidents, four cases; miscellaneous, three cases; severe impact, two cases; severe fire, one case.

DISCUSSION AND COMMENTS

This survey covers the period 1957 to 1961 for the accidents. Our actual shipping rate or the number of shipments that we are making, is current and covers period from October 1961 until March 1962, a six-month period. This was then converted to an annual rate. This represents a small number of samples.

As to trying to assign mileage, probably rail shipments would tend to be a longer trip than truck shipments but it looks like it is the same order of magnitude.

Dr. Leimkuhler will describe his study in which he looked at various carriers of other commodities and the accident frequency rate that they have.

In each case we have tried to get some sort of cost figure. Sometimes the radiological assistance team was called out or there was a delay and we do not have dollar costs on these. The most costly accident that we have had in the five years, that actually occurred on site where some containers ripped from the truck and went into the asphalt roadway and part of the roadway had to be dug up and replaced. This cost $8,700.

As to severity of the accidents studied, one headon collision of a truck where the passenger vehicle was completely demolished while our vehicle was only slightly damaged. The back end of the truck was not damaged.

I tried to pick out the very severe accidents, a collision, two vehicles, or turn over, or the trucks had jack-knifed and rolled off the road, things of this nature where you might expect if the container was going to be damaged it would be damaged in this type of accident. No impression as to the frequency of the maximum credible accident was developed.

The accident frequency rate includes all types of transportation and all accidents. We do have in these two reports a breakdown of the various modes of transport that are being used currently and the approximate percentage of shipments going by each of these.

The study includes only the shipments that originated at AEC installations. In some cases the AEC was transporting it, itself. However, I think in most cases the material was moving by commercial carrier. The criterion is that the shipment was made between AEC installations or originated at AEC installations.

Sometimes a carrier will load 10 to 30 individual packages on a truck or rail car.

The original intent of the study was to include each package as a single unit. However, in the mechanics of making the survey I think there are some cases where the shipment was interpreted as a car load. If it were made in a car load it was considered one shipment.

Oak Ridge which ships about seven percent of all our material, counted each package individually. It was our feeling that the other places where a car load lot is described as one shipment, would not seriously affect the numbers.

So we did not bother to go back and try to change that but it was intended that a shipment would be an individual outside package.

Session Chairman: Our next speaker is Dr. James M. Morgan, head of the Department of Civil Engineering, Virginia Military Institute.

THEORETICAL CONSEQUENCES OF ACCIDENTS

by

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The Johns Hopkins University
Baltimore, Maryland

INTRODUCTION

As a direct result of intense international interest in the safe transport of radioactive materials, the uncertainties concerning these ubiquitous cargoes promise to be a major topic in the 1960's. Historically, movement of all types of products in world trade generally has preceded the adoption of international regulations or regulatory standards. Accidents still can occur in any transport environment in spite of all precautions and expenditures to prevent them. To insure absence of accidents would require cancellation of all activity, an unlikely solution in any case.

The consequences following accidents involving radioactive materials in transport depend on such factors as accident severity, design and integrity of containers, ability of the carriage system to protect the conveyed item, nature and quantity of the material carried, the accident location and the specific environment in which the mishap occurs. The feasibility of assessing the consequences depends upon the answer to the question:

> "What are the effects in space, time and concentration following the accidental release of radioactive material in a given locale?"

Naturally, there is no single, all-inclusive answer to such a comprehensive query.

ACCIDENTS

Accidents are by definition unforeseen events; they can be studied in detail only after the event. Knowledge of accidents comes only from experience with them. While there have been accidents during interplant transfer with incidental release of low and intermediate radioactive materials, there have been, at this writing, no releases of the type postulated in this paper.

For our purpose we have assumed that an accident is any occurrence resulting in a release or suspected release of radioactive materials during shipment. Such events frequently are referred to as incidents. At the outset we were forced to assume that regardless of container design no accident, however extraordinary, could be ruled out as completely impossible and that ultimately some containers will release radioactive materials in transit.

The previous speaker has carefully covered the modes of transportation employed in this and other nations for conveying the materials of the atomic energy industry. He has also enumerated by type and categories of release the incidents which have already become matters of record.

THE HOPKINS COST STUDY

While the Johns Hopkins University group originally restricted its attention to two types of high level materials currently being shipped, i.e., (1) spent Materials Test Reactor (MTR) fuel elements, and (2) liquid reprocessing wastes generated in the recovery operations associated with fuel element reclamation, shipments of other types are amenable to the evaluation of consequences envisioned here. It was assumed that one MTR fuel element with its cooling waters was released from its cask, or that portions or all of approximately 500 gallons of a liquid reprocessing wastes were released from its shipping container. The characteristics of these materials and other pertinent information may be found in NYO-9772.

Our concern in the beginning of the study was to find a universally recognized measure of effectiveness. While consequences may be related in general terms to loss of life, property and occupancy, to temporary and "permanent" contamination, to denial of raw and finished products, or to intangibles such as public reaction, we were obliged to adopt a dollar effect of hypothesized consequences as our unit of measure.

In an early progress report (1), a model of the proposed analysis was set forth. Reduced to its simplest terms, it may be stated thus:

$$C_t = C_v + C_p + C_e + C_h \text{ where } C_h = P_a P_r c_c$$

and C_t = the total cost of transportation; C_v = cost associated with the vehicle (fuel, labor, etc.); C_p = cost of packaging (shielded containers); C_e = cost of escort; C_h = cost of hazard; P_a = probability of an accident; P_r = probability of a release from containers; c_c = cost of protecting or rehabilitating the environment following a release.

The terms of the model are related in a manner such that variation in one term may have a pronounced effect upon the others. It is by studying these interrelationships that the techniques of operations research are used to determine that combination of controls which yields minimum expected total cost while providing an acceptable level of risk.

The controllable costs, C_v, C_p and C_e, are relatively easy to evaluate, but this is by no means true of the "expected hazard cost" ($C_h = P_a P_r c_c$). Studies of the two probabilities, P_a and P_r, were also discussed in earlier reports. The probability of a release, P_r, is no doubt the most difficult term to evaluate. The last term of the expression for C_h, that is c_c, represents the dollar consequences in terms of cost of an accident involving a radioactive cargo. This paper attempts to evaluate that term.

CATEGORIES OF RADIATION RELEASE

In order to provide an initial classification for the possible varieties of accidents involving radioactive materials, the categories of release shown in Table I were established. Ultimately, the categories maybe revised, combined or otherwise changed for statistical purposes. The accident examples considered later have been referred to this classification.

ESTIMATES OF TOTAL COSTS OF ACCIDENTS

Certain tables of unit dollar costs based on specific quantities were prepared after corresponding with and visiting a great many sources of experience in accident evaluation, estimating and cost accounting. The tables were organized in a sequence reflecting the probable progression of costs as the accidents considered became more severe. These included: (a) monitoring and control; (b) decontamination; (c) losses; recovery and rental; (d) repair and replacement of property; and, (e) major sequential costs.

Values were estimated for losses as a result of shutdowns - for example, payroll losses and reduced values added by manufacturing - which might be incurred as a consequence of business interruptions following a release of radioactive material. The losses in income for "disabled" industrial units are static, in the sense that no account was taken of losses to other economic units because of denial of a given market, product, or service provided by the units originally shutdown. Economic losses from full or partial shutdown may vary considerably with time and in a non-linear fashion.

From these unit costs we feel that if an accident is postulated and conditions theorized a reasonable evaluation of the hazards cost can be made; one has but to set the conditions. We are aware that conversion of consequences to dollar values does not apply in every case because of such factors as severity of contamination, length of hospitalization, and possible failure to put local protective controls into operation immediately following an incident. Many factors are involved; but no attempt was made to define effects beyond the first degree of refinement in assessing consequences.

TABLE I

CATEGORIES OF RADIATION RELEASE

Category I	No release of radioactive materials. No radiation exposure or rise in surface count. Truck is delayed en route or is stopped. Suspected cask damage.
Category II	No release of radioactive materials. Radiation beam or significant rise in surface count. Cask integrity breached.
Category III	Release of radioactive material confined to the surface of cask or vehicle.
Category IV	Release of radioactive material to the ground or traffic-way with no run-off or aerial dispersal.
Category V	Release of radioactive material resulting in aerial dispersal.
Category VI	Release of radioactive material which enters a water-course either directly or after spilling to the ground or traffic-way.

TABLE II

ACCIDENT SITUATIONS

	Estimated Cost
Category I Shipment delayed enroute or cask damage suspected. Nearest AEC Office notified; one survey team member responds. Local police furnish round-the-clock surveillance. No special parking requirements.	$200- $500
Category II Cask surface radiation raised; no radioactive material released. Nearest AEC Office furnishes 2 survey-team members. Surveillance and parking required. One inch steel plates arranged in box-like fashion around cask to reduce radiation before shipment continues.	$2,000- $5,000
Category III Limited release of materials confined to cask and truck. Surface decontamination required. One inch steel plates arranged in box-like fashion around cask. Surveillance and parking required.	$5,000- $10,000
Category IV Fuel element and cooling waters released to the ground. Cask falls from truck and element falls to pavement. Long boom crane with steel plate shielding required. Area cleared of all persons for 2 days causing shutdown of wholesale establishments employing 200 persons. Extensive detour required. Driver hospitalized.	$20,000- $50,000
Category V Truck-trailer overturns and burns. One fuel element and cooling waters released to the ground. Fuel element does not completely burn, but approximately four square block area evacuated and hosed down to guard against stray particulate contamination. Crane and shielding required. Driver hospitalized.	$50,000-$100,000
Category VI Liquid release to water via ground. Entire contents spill to pavement surface and thence to flowing drainage ditch emptying into watercourse upstream from a community water supply intake requiring cessation of raw water drafting for 3 days. Extensive detour necessary.	$100,000-$200,000

ACCIDENT EXAMPLES

A set of assumed accident situations appears in Table II. The purpose in attempting to describe such hypothetical events and attach significant range of costs to them is two-fold. First, the examples represent an array of costs portraying the trends in severity for different possible situations; and, second, they attempt to portray realistically some cost estimates of the consequences of accidents. Where possible, the accidents have been described using factual information made available to the study or found in the literature. No attempt has been made to describe how the release occurred. In developing descriptions, the items occurring in one were generally carried forward to the succeeding at the same or greater intensity unless they were obviously not applicable.

While the foregoing accident situations are examples of localized monitoring, decontamination, recovery, repair and replacement, they do not indicate the financial loss to commerce and industry in the event there is a major incident or a spill to a waterway that would require denial of water to large centers of population. For example, suppose a city of 250,000 were to suffer first a 10% and then a total business, industrial and commercial shutdown due to treated water denial, for a duration in each instance of 2 days and then a whole week. Based on our studies of losses as a result of shutdowns, the indicated income losses in dollars would be:

10%		Total	
2 days	7 days	2 days	7 days
$430,000	$1,450,000	$4,300,000	$14,500,000

PHYSICAL CONSEQUENCES OF ACCIDENTS

In any analysis of theoretical consequences of accidents, ideas and suggestions will evolve for reducing the probability of an accident and thereby reduce the consequences. Imposing administrative controls is one suggestion; improved cask design and manufacture is another. A third would be careful selection of shipping and routing schedules and provisions for escort service. Again, we have assumed that however good the container design and however rigid the controls, there will ultimately be an accident with "serious" consequences. No attempt was made to describe how the accident or release occur; i.e., whether or not it resulted from collision, over-turn, rupture, puncture, etc.

Considerations have been made by many persons, agencies and research teams involved in predicting the fate of radionuclides re-

leased to the hydrosphere, lithosphere, and atmosphere. There have been some excellent meteorological investigations of fallout patterns and distributions of material dispersed in the atmosphere. While there are several studies currently underway, there have been, by comparison, few comprehensive analyses of the fate of materials released to surface waters. Disposal of liquid wastes to the ground is being studied at various locations and recently has been the subject of two conferences sponsored by the AEC, one at the University of California in 1959 and one at Atomic Energy of Canada Limited, Chalk River in 1961. The mixing, diffusion, adsorption, biological assimilation and other transportation and transformation phenomena operating in the environment combine to make prediction of the fate of released radioactive materials very difficult indeed.

Effects following certain releases to the environment could be lethal, injurious or harmful to man, could require medical attention for him with or without hospitalization and could require either temporary or lengthy evacuation from his dwelling and place of employment. His crops could be damaged or certain lands be denied him temporarily. The effect of loss of occupancy of either property or lands is difficult to determine. Real property may be damaged, requiring decontamination or demolition and ultimate replacement. Denial of equipment would require rentals; contamination or blocking of roadways would necessitate detours; denial of water may force cessation or reduction of commercial and industrial endeavors; top soil may have to be plowed under or removed.

Release of liquid, solid or gaseous radioactive materials to the environment is possible in todays transport scheme. Each is discussed briefly here.

Release to Natural Waters

Depending on the location and type of accident, liquid radioactive contaminants may reach surface waters by a variety of routes: by direct spillage, by direct drainage, by movement over or through the ground, and by soil erosion processes. The materials could be retained in sorptive earths, delayed in drainage by adverse slopes and vegetation, or taken up by plants.

In surface waters, they mix and diffuse and become attached to suspended matter and fixed surfaces. The physical process of sedimentation reduces suspended particulate activity, the magnitude of reduction depending partly upon the particle size and hydraulic turbulence. Chemically, some precipitation of radioactive material may be accomplished when a complex waste solution is introduced to natural waters. In addition, ion-exchange capacities of silts and bottom muds can reduce

the soluble activity level. Uptake by aquatic biota may also reduce radiochemical concentrations.

Unfortunately, only temporary benefit results from these natural processes. They can either spread or concentrate the activity and most of them will delay its movement toward the oceans. But the radioactivity is only stored in the streams and is not effectively removed.

Several hypothetical cases of the dispersion of 500 gallons of liquid processing wastes in rivers, tidal estuaries and reservoirs have been drawn in order to identify the patterns that might evolve through diffusion processes in the event of a release. The results obtained were not precise or completely definitive; they were intended only to represent tendencies and orders of magnitude.

It appeared that based on tracer techniques in flowing streams the mass of a tracer moves with a speed equal to the mean velocity of the water. Diffusion from a point source in reservoirs appeared to be quite slow. Therefore, with adequate warning, downstream intakes could be closed in sufficient time to exclude affected surface waters.

It should be noted that the ability of conventional water treatment facilities to remove radionuclides, in general will not reduce the activity in water to acceptable limits except where the initials levels of activity are very low.

The probability of a direct release to a natural watercourse of the high-level materials is admittedly very remote. The possible consequences should a damaged container or its contents enter a stream, reservoir or estuary must, however, receive some evaluation. There will be few if any places along the transportation routes in the United States where a vehicle will not be on the watershed of some municipal water supply.

Release to Soils

The rate of movement of aqueous solutions through soils will be governed by such variables as: porosity and permeability of the formations; the physical characteristics of the solution; the geometry of the method used for discharging the waste into the soil; and, the presence or absence of moisture.

Aqueous solutions percolating down through the earth undergo some treatment. Filtration in the top few inches of the soil may afford some particulate removal, but the most effective process will

probably be ion-exchange. A number of minerals have fair to excellent ion-exchange properties, particularly the clays.

The waste from a spilled cask in a flat homogenous terrain will spread out in a widening circle at a decreasing rate. As the waste is filling voids in the soil, the distance traveled, like the speed of travel, will be inversely proportional to the porosity and permeability of the soil.

Extremes of permeability are undesirable in most situations. Impervious soil will allow the waste to run off as a thin sheet and cover a wide area. A high permeability will allow a quick penetration by the liquid to undesirable depths. On hard-stands or impervious surfaces runoff would occur at the smallest slopes and an unconfined spill would spread erratically over surfaces that were not intended as drainage areas.

As far as is known, no pre-planned or accidental release of high-level liquid waste to the ground surface has occurred. In view of the general irregularities of most topography, the varying soil and subsurface conditions, and the presence or absence of man-made structures only a general approach to this subject can be made. Absorption coefficients and scattering of gamma rays in many natural environments are difficult to describe. However, any attenuation of gamma rays or beta particles by topography or structures would be most helpful in cleanup operations.

Aerial Dispersal

Inasmuch as the radioactive materials considered in this report are in a solid or heavy liquid state, it is evident that significant aerial dispersal of the contaminants would occur only as the result of a fire, the contamination in this instance representing chiefly the volatile constituents of the materials released because of the temperature rise.

The incidence of fires in severe traffic accidents is not an uncommon phenomenon. The ignition of the prime mover's fuel supply is certainly the main cause of these traffic fires. Once again the probability of a combination of events (i.e., traffic accident, release of materials and a fire) limits the credibility of such an incident, but, it is still possible. The possibility also of meltdown because of self-generated heat after the loss of coolants in an accident would create another hazardous situation.

The nature of the contamination from aerial dispersal would be akin to that from any fallout pattern. The exact analysis of the fall-

out pattern is difficult, involving numerous parameters, and requiring elaborate laboratory and field tests for any given materials to be considered. An exposed person in the path of a cloud could inhale the particulates, have them deposited on his clothes and body and might also be affected by that deposited on neighboring topography or structures.

Judging from the results of controlled fuel element burn tests, the fallout of particulates should not produce alarmingly high depositions. Beard (2) estimates that in a severe fire involving fuel elements less than 10% of the total materials would be released. Outside the immediate area of the source, the concentrations of particulate matter transported downwind might indicate the need for some protective measures at distances removed from the scene of the accident. Some evacuation is likely, and also precautionary decontamination, probably by fire hosing. The chief long term hazard of aerial dispersal might be the contamination of crops and grazing areas.

Firemen, and others in close proximity to the fire, must be protected with special clothing and equipment. Procedures to be employed for monitoring exposure rates, providing post-exposure personal decontamination and disposing of clothing and gear must be planned and practiced in advance.

CONCLUSIONS

Theoretical consequences of accidents involving accidental release of radioactive material are practically numberless. While effects subsequent to accidents may follow vague or well-established patterns, the numerous conditions under which accidents may occur, coupled with combinations of environmental factors, almost defy too rigid a classification of hypothetical consequences.

What is probably next needed is a thorough, practical examination by biologists, chemists, economists, engineers, health physicists, indemnifiers, meteorologists, soil scientists, and surface and ground water experts to assess actual and practical consequences on a task force basis.

REFERENCES

(1) Thompson, J. T. and Leimkuhler, F. F., An Operations Research Study of the Transportation of Highly Radioactive Materials, Progress Report, NYO-7832, The Johns Hopkins University, April 1959.

(2) Beard, G. Victor, Fuel Element Burn Test, as reported in TID-8206, February 1958.

Remarks by Dr. Morgan: About my present affiliation I would like to say that this particular paper is the product of some research by Mr. John W. Knapp, who is a graduate student at the Johns Hopkins University, and Professor James Thompson, whom you will hear and see later.

The Johns Hopkins University began a study of an operations research study of the transportation of highly radioactive material in a small way in 1957. There have been several reports that have resulted from this particular study and this is one of them.

Dr. Leimkuhler will comment on another. The consequences that follow any accident involving radioactive material depends on accident severity, the design and integrity of the containers, stability of the carriage system to protect the conveyed item, the nature and quantity of the material, the actual location and, of course, the environment in which the mishap occurs.

Suppose we look at category 1. In an accident situation a shipment is delayed on route or cask damage is suspected, the nearest AEC office is notified. In our discussion we set up a survey team to help in the event of an accident which consists of four people.

We gave them the general service classification of federal employees. We tried to find out their daily salary. We tried to find out the cost of bringing this particular group 500 miles or "X" miles.

In this particular case maybe the driver was incapacitated or could not stay. We had to have a policeman come and stay around the vehicle but no special parking requirements were involved.

Here we figured the cost of the simplest type of accident to be from 200 to $500. As we increase in severity the accident and the situation, going from category 2 to category 6, you can see that our estimated cost rose considerably and the estimated cost here we would say varied from $200 to $200,000.

Now believe me, gentlemen, if we have been criticized for anything, we have been criticized for putting dollar values to the accident. Since they have not occurred, naturally, we must and had to hypothesize on what we thought each of these types of accidents would involve.

Going to our cost tables, using the unit cost, our investigation came out with these numbers. It is quite possible that if you wish to theorize yours and to set the conditions for an accident you could use our cost tables and you might come up with something that is much more severe than this or it may be less severe, depending on the conditions that you set. Of course, you will see that the category 6 which we figure to be the liquid release to a stream would be the most severe. Possibly, if a fuel element or some other solid burns and releases radioactivity, such that a fairly reasonable area must be evacuated and not re-occupied for some time, then, of course, you might possible find category 5 would be more costly than 6.

The Commission has spent a great amount of money in making investigations concerning the release of radioactive material to the environment. Many of these are theoretical while on the other hand, a great number of them practical. As far as the transport environment is concerned, we must really confine ourselves to the heightosphere, lithosphere or the atmosphere so that if any particle matter gets out it goes into the air, ground or water. It has been my good fortune to attend a great number of meetings such as this at which these particular environments were investigated and discussed.

There have been burning tests at the National Reactor Testing Station, and possibly other places, of MTR and other types of fuel elements that have been subjected to extremely high fire heat.

There have been several cases in which liquid wastes have been advertently discharged to the ground to check the pattern that they would follow or the paths that the liquid would follow if a liquid were released to the ground.

Then, of course, there have been some very excellent but not too many comprehensive surveys of release whether it is in the air, to the ground or to the waterway, will follow certain predictable paths. Now since all types of radioisotopes have not been released and since all environments have not been fully investigated, we really cannot make a too rigid classification of what would happen in the event of an accident in which any type of radioactive material was released during transportation. But the effects of these as postulated by the dollar values can at least be looked at from a reasonable and a rational platform.

There have been some studies that have been made assigned to be the terrific values, values in the millions, hundreds of millions and possibly almost up to the billions of dollars of damages following certain accidents. Of course, I am sure that you would appreciate that here we were talking about a release following a reactor incident and it was for this reason that we have to look very closely at our dollar values to try to portray what we thought realistically would result in what may seem to be fairly low dollar values.

I would like to say that the Atomic Energy Commission has conducted throughout the United States in about a hundred or possibly more than a hundred cities the so-called Fire and Safety Courses. We have been in contact with the municipal officials and the state officials in the states and in the municipalities that have been so served.

I will say this, that there now exists in the U. S., particularly in the large metropolitan areas, well-trained groups of firemen and policemen and in some cases other municipal officials who are well-trained in handling an incident provided it is not too large or provided it is not too catastrophic, if that is the term that should be used.

There has been very great attention given these types of courses. As the AEC continues in this respect there will be trained more and more people throughout the United States, particularly in this area who can help or help cope with incidents or accidents of the type that we have up here. This is particularly true of the fire personnel.

Now, in conclusion, I would like to say that the Theoretical Consequences of Accidents involving the accident release of radioactive material are practically numberless. I am sure you can think of many I have not mentioned or that are not in this paper.

Fires subsequent to accidents may follow vague, in some cases, or well-established patterns. The numerous conditions under which accidents may occur, coupled with combinations of environmental factors almost defy too rigid a classification of the hypothetical consequences.

I am sure you can think of countless isotopes to be conveyed in a great number of containers in different types of transportation environments, rail or air or water, and then if you add to that the locale in which the accident occurs, you can see it becomes a great job to codify or classify all of these.

I would like to recommend that probably what is next needed is a thorough practical examination, not necessarily following the operations research approach, but by biologist, chemists, economists, engineers, health physicists, metallurgists, surface and ground and water experts, to really examine the practical consequences on a task force basis.

This may be a tremendous problem. It is quite possible that it is. It is quite possible that some time in the future there will be an accident that could be described as catastrophic. Whether we describe it as catastrophic on a dollar basis or on the basis of persons involved who may be injured, that is something else, but I think it would be very interesting to look at this whole thing on a task force basis.

Session Chairman: I would like to introduce Dr. Leimkuhler, also formerly connected with the Johns Hopkins group, presently Associate Professor of Industrial Engineering at Purdue University.

Safety Considerations in the Transportation of Highly Radioactive Materials - An Operations Research Approach *

by

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Operations Research has concerned itself traditionally with decision problems in operational situations, where the decision-maker has only limited knowledge and control of the environment. For there to be a meaningful problem, there must be more than one alternative course of action open to the decision-maker. This set of choices or strategies is the first component of the problem. To be meaningful the choices must have different outcomes or payoffs, and the decision-maker tries to find that strategy which maximizes, minimizes, or simply optimizes the payoff. In situations where the strategy doesn't fully determine the outcome, we can identify a third component, called the environment or state of nature. The strategy selected, together with the state of nature which takes place at the time of action, results in a particular payoff.

Decision-making under Uncertainty

This very simplified statement of a decision problem can be used to demonstrate some interesting features of the problem we are considering today, that of the safe transportation of radioactive materials. Consider a hypothetical situation in which the shipper has only two courses of action open to him: either he exercises a certain amount of control or no control over the shipment. To be

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more specific, let us assume that either he provides escorts or he doesn't provide escorts for a particular shipment. Furthermore, let us allow only two states of nature to occur: either the shipment meets with an accident of a certain type or there is no accident and the shipment reaches its destination in good order.

We now have the makings of an interesting decision problem with two strategies and two states of nature, or four possible combinations of factors. The next step is to assess the payoffs for each of these four situations. For simplicity, I have chosen the four payoff values shown in Table 1, which represent negative payoffs or net cost. Here the escort has a relative cost value of 10, and unescorted accidents cost 1000, but escorted accidents only cost 100. The problem is to find the strategy which optimizes the decision-maker's position. Should he use escorts?

TABLE 1. Negative Payoffs for a Hypothetical Shipment

	Accident Occurs	No Accident	Maximum Cost	
Escorted	100	10	100	Minmax Solution
No Escort	1000	0	1000	

As the problem stands, with no further information about the occurrence of accidents, there is no simple solution to the problem. However, a solution has been proposed which has its theoretical origins in game theory and has found wide acceptance. This is Wald's "minmax criterion" (4) where the decision-maker considers the worst that can happen to him under each alternative and then chooses the best of the worst. It is interesting to note that this appears to be a criterion used in the appraisal of reactor safeguards, where attention is focused on the minimization of the consequences from maximum credible accidents.

It can be shown that the minmax solution to the above problem is a very good solution if we interpret "mother nature" as an opposing decision-maker who is out to ruin the shipper, and is sure to produce an accident. For this reason, the minmax is considered an ultra-conservative criterion for action. What happens if the prob-

ability of accident is something less than certainty, i.e., its value is less than unity.

Decision-making under Risk

Normally, with a knowledge of accident probabilities and for a large number of repeated shipments under similar conditions, the criteria used is that of expected value. For example, if the probability of accident is 1/10, then we would expect nine out of ten shipments to be accident free. The expected cost would be (1/10)(1000) plus (9/10)(0) or 100 without escorts, and 19 with escorts. On comparison of these expectations, the use of escorts is still the best policy. In Table 2, the expected values are determined for progressively smaller probabilities of accident, and it is interesting to note that when this is greater than 1/100 the expected values begin to favor the no escort policy.

TABLE 2. Expected Costs for Various Accident Probabilities

Acc. Prob.	1/10	1/100	1/1000	1/10,000
Escorted	19	11	101	1,001
No Escort	100	10	1	0.1

Granted that the example used is a gross simplification of both reality and the theory of decision-making, it does serve the very valuable purpose of demonstrating quantitatively how there can be differences of opinion regarding the application of controls to uncertain situations. However, as knowledge is accumulated and better predictions can be made about the behavior of the environment, there should be a tendency to shift from decision-making under total uncertainty to decision-making under an appraised risk.

An Operations Research Study

In the study of truck transport of highly radioactive materials, which was made at Johns Hopkins University (7), an attempt was made to appraise the risk to such shipments and to find optimal control policies. By limiting our attention to shipments by tractor-semitrailer, we were able to collect good data covering their frequency of involvement in highway accidents. The mean accident rate for truck shipments of radioactive materials was placed at 3.63

accidents per million miles, or approximately 27,500 miles per accident. (3).

Furthermore,these data showed a clear pattern of rising accident rates with increased traffic congestion on the highway and inclement weather conditions. Two possibilities for control are suggested: routing shipments over less crowded highways, and delaying shipments during periods of unusually high accident frequency. Mathematical models were constructed to show how operating costs would be changed under such controls, as well as how the accident rate would be reduced. In order to make a final choice, however, it was necessary to hang a dollar sign on the consequences of accidents.

Through a careful assessment of the available data on tractor-semitrailer accidents, it was determined that the dollar damage to the truck was a very good indicator of the severity of accidents. This analysis proceeded in two directions. First, it was possible to relate truck damage to the physical characteristics of an accident, and a quantitative expression was derived which predicts damage as a function of the mass, speed, and direction of impact. These latter factors could be related, in turn, with highway characteristics. The net result of this part of the investigation, therefore, is to show quantitatively how control of the highway environment can affect the truck damage expected in accidents. By combining this with the accident rate analysis, models were obtained that show how the risk of truck damage (damage per mile) varies with route selection, scheduling, and speed control.

The second part of the theory constructed about truck damage is an attempt to predict total accident cost as a function of damage. Some of the best authorities (5) on passenger car accidents have concluded that vehicle damage is the best indicator of such accident consequences as injury and death. From the data available it was found that the total direct cost of highway accidents for all types of truckers is almost directly proportional to the truck damage, with a ratio of about four-to-one (2).

For want of actual cost and damage data on truck accidents with radioactive cargos, the simulated accident experience from the

study by J. M. Morgan (6) was used. Here, again, it was found that total cost was directly proportional to truck damage; but the cost-to-damage ratio was of the order of twelve to one or three times that found with non-radioactive accidents. A third and final estimate of this ratio was derived from the existing insurance premiums on shipments of high-level materials, and in this case the ratio was higher still, being three times that of the simulated accidents and nine times that of normal truck accidents.

As might be expected, both truck damage and total accident cost show considerable variability with proportionally more accidents in the low cost category. This same pattern was found for many other disaster situations, such as, floods, fires, tornadoes, and earthquakes; however, the cost spread in natural disasters was found to be considerably greater than that of traffic accidents and major fires. In all cases, the lognormal distribution was a very good approximation of the cost patterns. Whether or not radioactive accidents will tend to have a higher cost spread (variance) than non-radioactive accidents is an open but important question.

Balancing Safety and Economy

From the analysis performed, the mean total cost of truck accidents with radioactive cargos was estimated to range from about $5,000 to $40,000 per event, with $13,000 as a middle estimate (1). Less than one per cent can be expected to range up to and beyond a million dollars, if the high estimate is used. About ten per cent of the accidents would have costs greater than two times the mean values using all estimates. When these figures are combined with accident frequency, the estimates for the mean risk are $0.016, $0.043, and $0.144 per mile, respectively. By using the convention of doubling the risk to get a conservative premium value for the losses, the risk values would be $0.03, $0.10, and $0.30 per mile approximately. The lowest figure applies to non-radioactive truck shipments, the next highest is based on simulated accidents, and the highest is based on insurance rates with highly radioactive cargos. These figures take into account the inherent variability of both accident frequency and severity, according to the theory constructed and the data considered.

The decision to exercise controls over shipments of radioactive materials can now be described as the balancing of control costs against reductions in accident premiums. Since the premium is said to be proportional to the accident rate and the mean truck damage, percentage reductions in either or both of the latter will yield similar reductions in the accident risk and premium. Such reductions were determined for the routing of shipments over alternate routes, for reducing truck speeds, and for scheduling shipments so as to avoid unfavorable weather and traffic conditions. In addition, the cost of such controls were estimated and compared with the reduction in dollar premiums in order to find breakeven control levels.

Application to Control Policies

In general, it was found that the degree of control, which could be justified in this manner, was highly dependent on the cost-to-damage ratio used as well as the intitial conditions of the shipment considered. Shipments already moving under favorable highway conditions did not call for additional controls such as speed reduction. Such money would be better spent in identifying those shipments moving under very unfavorable road conditions and then subjecting them to additional controls. On the other hand, if the cost-to-damage ratio is no greater than that experienced by normal truck traffic, then it would be difficult to justify any of the controls considered in almost any type of highway environment. This conclusion would also raise the question of whether additional expense could be justified for other types of control effort such as improved container design. However, the foolproof container would also eliminate the need for operational control. It should be noted that the cost of such control measures as container improvement and centralized accident reporting and control systems can be prorated over many millions of truck miles; and relatively small reductions in accident risk may be sufficient to justify a large measure of such control.

In summary, as more knowledge is gained about the accident risk to shipments of radioactive materials, control policies can be expected to move from a cautious "minmax" type of decision to a more

flexible analytic basis such as expected value, which incorporates much more of the information available. The information needed for analytic decisions can be drawn from basic research, experimentation, testing, analogous operational systems, and, best of all, from actual experience. There is a real need to capitalize on the experience which is being accumulated daily, and this calls for a good system of accident reporting and analysis. With such operational data, it should be possible to establish performance standards and to identify shipments with exceptionally high risk patterns. In the latter case, various operational controls are available for use on an experimental basis, which promise to reduce the relative accident risk without incurring unusually large capital or operating expenditures.

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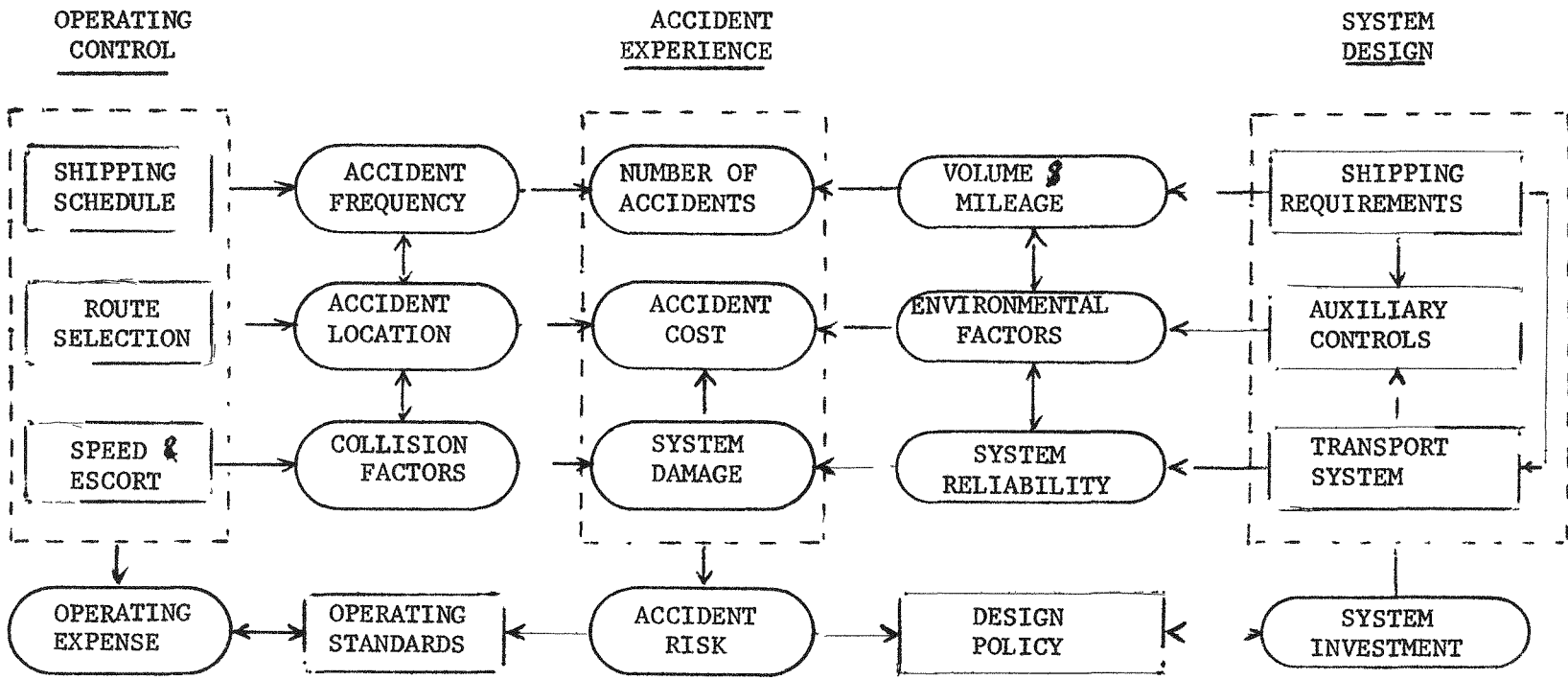


FIGURE 1 SCHEMATIC MODEL OF THE TRANSPORTATION OF RADIOACTIVE MATERIALS.

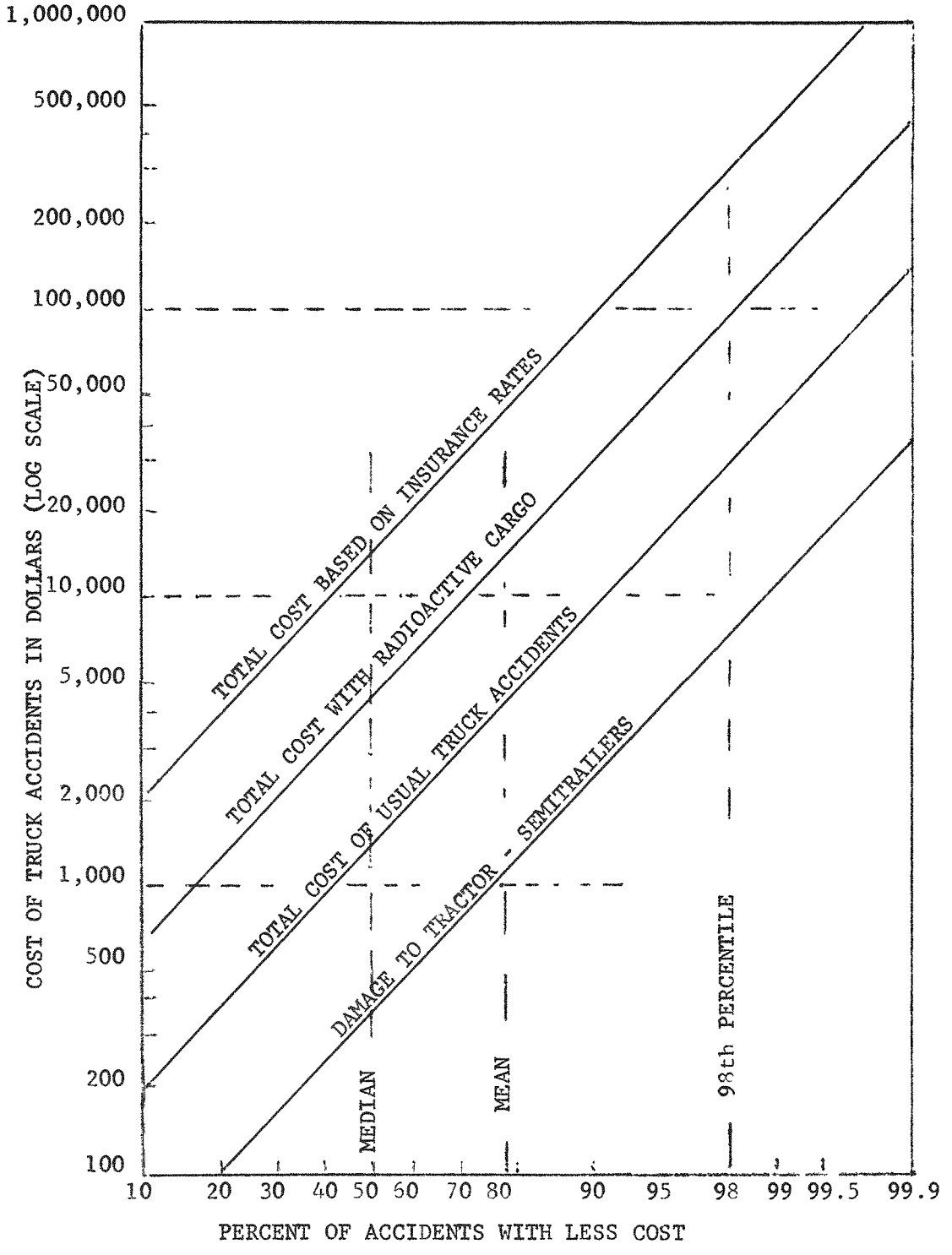


FIGURE 2 ESTIMATED LOGNORMAL DISTRIBUTIONS OF THE COST OF TRUCK ACCIDENTS

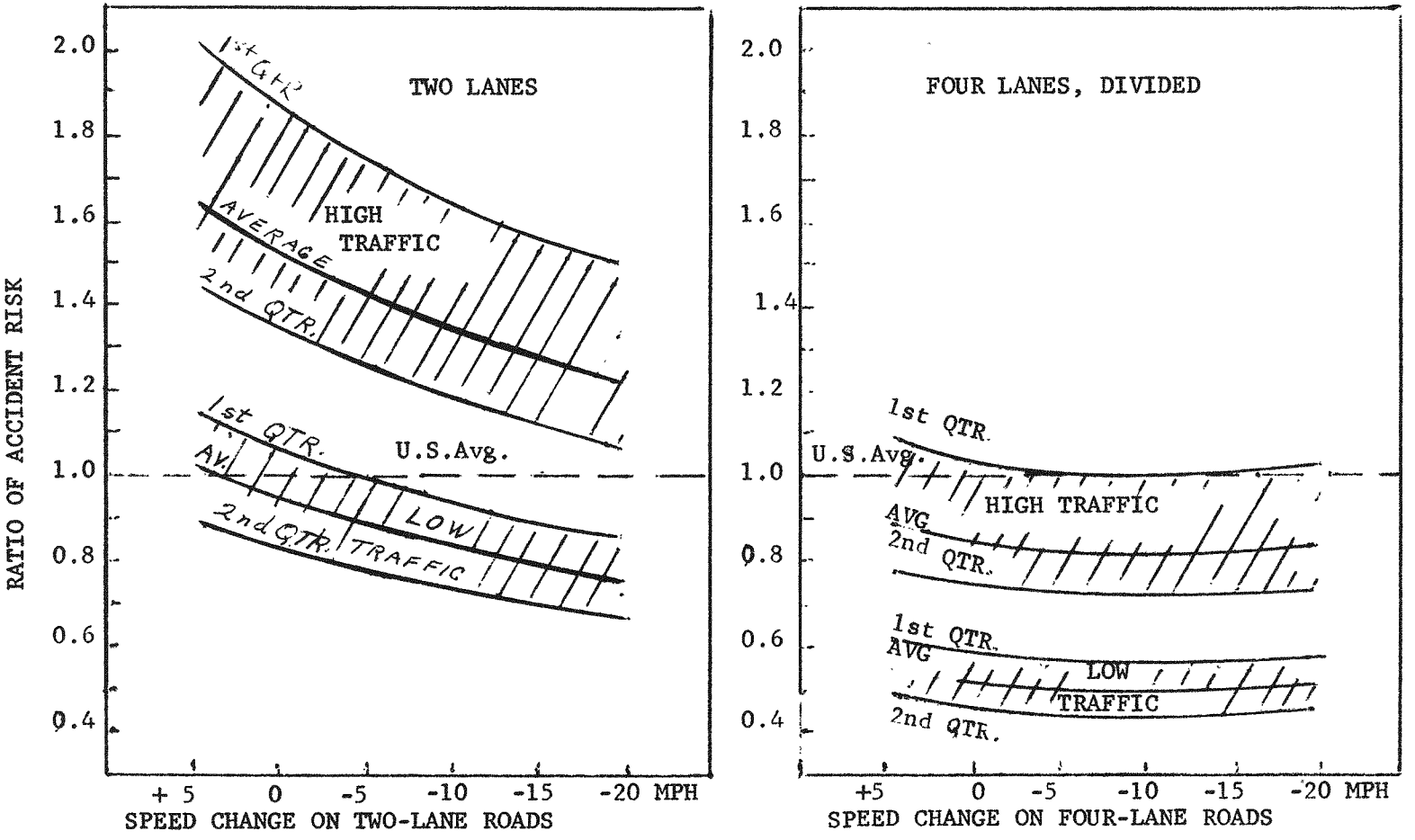


FIGURE NO.3 RATIO OF ACCIDENT RISK TO U.S. AVERAGE FOR CHANGES IN FREE FLOW SPEED ON VARIOUS HIGHWAYS UNDER FAVORABLE AND UNFAVORABLE SEASONAL CONDITIONS.

(Comment by the Office of Transportation of the Department of the Army). When the Army first started moving nuclear weapons which has some radioactive materials, we controlled the truckers to a speed of 35 miles an hour, not to exceed that rate. Three or four months ago I accompanied the escort in front of the truck containing the material. The driver maintained the 35 mile an hour speed limit. After riding on a two-lane highway for about 20 miles, I told the escort officer to pick up his speed because behind us was a long string of cars and trucks, several of which had made attempts to pass us and some did. But I didn't know whether some of them were going to pass us or whip us over in the ditch. So we immediately lifted those restrictions and let that escort officer-based on the road conditions decide the speed. The only restrictions now are on these super highways with a posted speed of 65, we now limit them to 50 or 55 miles an hour.

Mr. Leimkuhler pointed out that from his charts the relative risk increases on super highways as his speed is reduced. This is because you are increasing the net velocity of a rear end impact by doing this.

It was noted that the categorization of accident in both Mr. Leimkuhler's paper and Mr. Patterson's paper were based on the transport of fuel elements or solutions of mixed fission products.

In regard to other types of accidents, the ICC makes a most thorough accident study particularly of truck accidents. There have, unfortunately, been a number of accidents in transportation of other goods particularly propane in the last few years. One of the more recent ones involved a shipment of liquid helium resulting in much more than minimum damage to the vehicle, itself.

As to whether a precise analysis of the ultimate cost of these mishaps involving truck transportation is concerned, frankly, we do the best we can to assemble the facts as to the immediate costs and to put them down.

In regard to studies of accidents involving chemicals, the Bureau of Explosives have published results of studies of accidents in the transportation of dangerous articles for a little over 50 years.

This week there was a rail accident in which a lot of chlorene was released very suddenly. This is the second such accident in the history of the transportation of chlorene in tank cars and it still has not been investigated, so I will not say much about the recent one.

The previous accident was a case where a tank car designed for a certain pressure was punctured. We can learn a lot from it because tank cars have been in numerous accidents through the years and that is the first one which has ever been punctured. This gives some idea of the frequency of a certain type of design that I think is useful. Our purpose in recording accidents is to study the frequency of accidents and what can be done to prevent them.

There was the case of the heavy containers of chlorene that went into the Mississippi River. The AEC also has had experience in which a container went into the Colorado River back in 1958. They were able to take the container from the Colorado River just in pretty much the same manner that the Corps of Engineers took the chlorene containers from the Mississippi River.

The category No. 6 accident involving release to a water supply appeared to be the most dangerous. If the large volume of chlorene gas had gotten into the Mississippi River it would have been a catastrophe.

The release from accidents is associated with other agency operations and research is going on in this area at the present time. This is largely conducted by the U. S. Weather Bureau under a special project of the environmental study group of the Weather Bureau. This has to do with study of the atmospheric motions and their effect on transporting all sorts of material. We are concerned with operating reactors, with accidents and other phases of Atomic Energy Commission operation. The whole field of study is the study of meteorological effects through the whole spectrum of mechanisms that can transport radioactive material or any other toxic materials from one point to another.

So there is study going on although not particularly related to transportation at the present time.

Mr. Leimkuhler indicated that the effect on the community, the impact of an accident on a community or adverse public relations are important to consider. Decision making on the cold figures present may be insufficient because of these factors. Whatever payoff you put in payoff figures is the type impressing the true value to the decision-maker.

He doubled the expected cost estimated and called this a premium on the risk. On insurance policies the premium you pay does not all go back to paying accidents. Only half of it does. You have to adjust these figures.

It was noted that the paper discussed the speed and the variation in the package. Varying the tie-downs is being considered.

Mr. Leimkuhler indicated that the type of strategy he was talking about was a departure from the original cost model that Dr. Morgan had on the slide. That was the original model considered but abandoned because of the amount of research needed.

To get an answer Leimkuhler took a total cost figure and the probability of achieving such a total cost rather than what goes on in between. All the various things that created this cost were sidetracked. That will have to wait for research.

It was suggested that the best system of reporting seen in Leimkuhler's search for data was the ICC Truck Accident Reporting system. The ICC has a policy that a serious accident, one involving a fatality, for instance, has to be telegraphed to the ICC headquarters in Washington within 24 hours.

In addition, notice is given locally and a local field and trained investigator is on the scene of the accident as soon as possible. Photographs and an extremely well-documented report of the accident, court witnesses, and other data that is collected, all newspaper clippings, are in that file. That was their greatest, most valuable source of data. This would even happen if the accident had only $100 damage in it. Also, if nothing happens to the truck, but if somebody was killed.

For rate reasons the ICC collect all mileage figures so that to compute an accident rate on a mileage basis can be easily done here.

If you are going to report all accidents in some detail of, say, $100 or $200 accident level, if you are going to have trained investigators on the scene of any serious accident, with cameras and everything else, and if you are going to record the mileage data that is being generated, the shipment mileage, I would say you are covering everything.

The cost figures are from two sources. The Bureau of Public Roads is making a study of this for traffic accidents. The other types of data came from the Red Cross and was the disaster cost information. These two sources were used to arrive at a hypothetical loss figure.

(UK Comment) We have suggested the following definition of "incident": "An incident means an accident resulting in one or more of the following: (a) escape of radioactive material in such a manner as to cause exposure of persons exceeding the levels referred to in the International Atomic Energy Regulation, Section 4.2. Or contamination exceeding the levels of the "IAEA" Regulations, Section 11. (b) Emergance from a package of radiation having an intensity exceeding that permitted by the section of "IAEA" Regulations under which the package is being conveyed. (c) A rise of temperature above the levels prescribed in the IAEA Regulations, Section 16 and, (d) achievement of a critical assembly."

I would like to add to that that an incident is not necessarily a dangerous occurrence except when a criticality is involved. Of course, that is a catastrophic happening.

There is one point about that definition. We have related it to accident. Of course you can have an incident of that magnitude without an accident. It can occur from the normal condition of transport through some failure of the container, through vibration or humping, which we would not call an accident.

SESSION II - REGULATORY STANDARDS FOR SHIPPING CONTAINER DESIGN
MONDAY AFTERNOON - DECEMBER 3, 1962

Mr. Robert Lowenstein, Director of the Division of Licensing and Regulation of the U. S. Atomic Energy Commission, Session Chairman, presiding.

Session Chairman: There is probably no area where the need is so great as in the field of transportation for agencies to adopt regulatory standards, that is to articulate the bases which they will use for the approval or disapproval of containers. The transportation of commodities in commerce involves the interests of a great many government agencies and private organizations. On the state level they are almost too numerous to mention but, of course, they include many agencies in state governments, county and municipal governments, bridge, turnpike, tunnel, port authorities. On the Federal level you have heard them referred to before and many of them are participating in this meeting; the ICC, AEC, Coast Guard and so forth. When transportation takes place in international commerce the domestic situation is duplicated by the number of different governments that became involved.

Finally, in addition to the various government agencies, international organizations, there is the interest of the various private groups that are involved. Carriers must know and understand the risks which they are being asked to assume in transporting dangerous commodities. The employees of carriers must assess the risks which they are being asked to take. Cask and container designers and shippers must know the requirements they will be required to meet, and frequently they must know it in advance by a period of years before a proposed shipment will take place.

Insurance carriers need to be satisfied that their policy holders are not taking unnecessary risks at the expense of the insurance company. And the general public and the people, from whom we hear the leastest but count the mostest, the people who live and work along highways, must be given confidence

which is justified by the activities in which government agencies, carriers, cask designers are engaged, to assume that these commodities will be carried safely and these standards must be articulated in a way that the public will understand.

Taken together these are the reasons, briefly, for regulatory standards, the subject of our next panel discussion. To introduce our next speaker to this group would be something like introducing Henry Ford to a small meeting of automobile manufacturers. Mr. Thurber George will discuss for us Interstate Commerce Commission regulations.

DEVELOPMENT OF INTERSTATE COMMERCE COMMISSION REGULATIONS

by

Thurber C. George
Director and Chief Inspector
Bureau of Explosives
Association of American Railroads

Before embarking upon any discussion of the I.C.C. Regulations applying to the transportation of radioactive materials, I should like to briefly review the origin of the Bureau of Explosives as well as the origin of the I.C.C. Regulations. It is hoped that those who have heard the story before, and I am sure many of you have, will bear with me while I give a reasonably accurate summary in as brief a manner as possible.

About fifty-six years ago, and shortly following a few disastrous explosions and accidents, our railroads felt that they had had adequate demonstration of a crying need for some standard methods to assure safe handling of explosives. As an outgrowth of their sad experiences, the Bureau of Explosives was formed, and using that embryo as a clearing house or central location for gathering data, a few rather simple rules were established for the handling of explosives. These rules were largely in the form of a gentlemen's agreement between member railroads and representatives of the explosives industry who saw the benefit that would be derived if further accidents could be avoided.

As time went on these rules were enlarged upon, and dangerous articles other than explosives were included among the items so regulated. In addition, the railroads and other members of the Bureau saw the desirability of having the practices which had been laid down given the force of law in order that they might become standard throughout the manufacturing and transportation industries. As a result of this early interest in the matter, an Act of Congress was passed empowering the Interstate Commerce Commission to write and enforce regulations to govern the transportation of explosives and other dangerous articles. To a large extent the rules which had already been established were adopted and have since been enlarged upon to include new materials and provide for new packing methods.

From the foregoing you will see that the regulations are not static and are constantly undergoing changes to meet the current requirements. As a result of this activity, the work of the Bureau of Explosives has grown but it still serves the purpose for which it was originally organized, and continues to act as an educational organization acquainting shippers and carriers with the best-known means of assuring safety in transportation.

While the Bureau of Explosives is not a Government agency, the Interstate Commerce Commission is authorized to use the services of the Bureau by the Act of Congress under which the regulations are codified.

All that I have said about the Bureau of Explosives and the I.C.C. previously is based pretty much on hearsay or facts that I have found in our files. From now on I will talk about things that have occurred or developed in my own experience and, therefore, I will be better able to assume responsibility for any statement of the facts. I came to the New York Office in 1943 through the courtesy of my predecessor, Mr. H. A. Campbell, who was at that time Chief Inspector.

I had had little more than a year to become acquainted with the workings of our headquarters' office when the Interstate Commerce Commission decided that something would have to be done about providing safe means for transporting a then relatively new item in commerce, namely the radioactive isotope. It is true that radium had been shipped for a number of years by rail express under conditions agreed upon by the Railway Express Agency and an interested group of shippers. As early as 1945 it was very apparent that ever increasing quantities of radioactive materials would be shipped in the years to come.

It long has been the policy of the Bureau of Explosives, when called upon to develop regulations or changes in regulations which affect any industry, to consultwith members of the industry for the purpose of determining what practical regulations could be devised to best serve the interest of safety and the needs of the economy. If this policy were not initiated by the Interstate Commerce Commission, it did concur with us and as the statistical records of the Bureau will show over the years since its inception it has been eminently successful. Thus it was that the Bureau, in trying to form a group or committee to consider the matter of regulations for radioactive materials, gathered together some persons who already were engaged in the shipment of such materials, and persons who had had occasion to study the possible or probable hazards of handling such materials. At least two meetings were held in the offices of the Bureau, a committee was formed under sponsorship of the National Research Council and headed by Dr. Robley D. Evans of the Massachusetts Institute of Technology. I would urge anyone who has an active interest in the history and development of the regulations to refer to Nuclear Science Series Report No. 11, which was revised in 1954 and reprinted in 1960. This report contains much more historical information than I could properly present at this time. It is in my opinion, an extremely fair and concise presentation of the consideration given the subject of transportation of radioactive substances.

In spite of the care that was used and the foresight of the committee who worked on the regulations some 16 or 17 years ago it would be foolish to assume that every contingency was foreseen and that no change in the regulations is now necessary. It seems equally unreasonable to assume that the regulations have been deficient in providing reasonable safety in transportation when one views the safety record which has been established in the transportation of these materials since the regulations became effective. From this it appears to me that it is not an over simplification to state that two things are apparent at this point: First, the requirements of the regulations as they apply to the classification and packing of radioactive materials are not in need of a complete revision and Second, certain amendments to the regulations are necessary to provide for the changes in conditions that have occurred since the regulations were first written. To find ourselves in this position is not a new experience in the history of the transportation of explosives and other dangerous articles and it is, in fact, common to the great majority of materials being transported today. I would not hold that just because we have always done something a certain way we must continue to do it that way. It has been the practice, and a very successful practice indeed, for the Bureau of Explosives to work closely with shippers and/or shippers' associations in studying needs for changes when proposed by them or by an interested carrier with a view to arriving at a mutually acceptable amendment to the regulations which is then submitted to the Interstate Commerce Commission, published in the form of a Notice to the public and adopted in due course, if no substantiated objections to the change are filed. Since the Interstate Commerce Commission is concerned with the domestic shipment of dangerous articles, it has always given full and careful consideration to the needs of our industry and our modes of transportation. In doing this, the Commission and the Bureau of Explosives have been fully aware of the fact that conditions might differ in other countries. We, in the Bureau, have felt that these differences cannot be too great and generally can be accommodated through a free interchange of ideas. This can be done without making our regulations identical with those of other countries and, in fact, considerable progress already has been made in that direction with regard to transportation of dangerous articles by air.

Even with the very simple regulations presently effective, there has been considerable difficulty on the part of shippers in understanding the requirements. Some of the difficulty, no doubt, is due to an inability to realize what the regulations attempt to accomplish. To properly understand the purpose behind the various requirements of the regulations we must momentarily disregard the manufacture and use hazards and consider only the risks which may develop in transportation. It also is necessary we recognize that while the risk to persons engaged in transportation is considerably less than to those in the industry because of the limited exposure; the risk to property may be somewhat greater since materials in transportation are subjected to exposure to various types of accidents which could spill or even scatter the material unless adequate packaging is used.

To better illustrate my point, I will ask you to consider the subject first from the standpoint of human tolerances. Let us suppose that one of our installations prepares and offers for transportation in a single day twenty or thirty packages containing radioactive materials. In preparing these shipments it will be necessary for certain personnel to be exposed to radiation from these packages, and the next day these same personnel will be exposed to further radiation in preparing other shipments or in other work around the operation.

In the instance of shipments which are picked up at plants, it is quite possible that the same express messenger picks up shipments every day in the week, but he is not exposed to radiation from the packages for eight hours of every day in the week, as some of the plant personnel may be. It is doubtful if he has shipments in his vehicle for more than two hours, and if he does have them longer than that, it is quite likely that he is not in the vehicle for the entire period. He then delivers the shipments to an express office, or in the case of motor carrier shipments to some central station where they may remain for two or three hours.

At points where any appreciable quantity of such materials is handled we have made certain that persons engaged in handling the material are instructed not to place the packages near where they work, and here again the packages are only held a few hours before being forwarded, thus limiting the exposure of personnel to less than their full working day.

As soon as the shipments are placed in vehicles for actual transportation, the amount of material is automatically diminshed by the very fact that the destinations of such shipments are varied, or if all packages do go to the same destination, it will probably be several days before another shipment is made.

I have gone into the foregoing detail to establish that persons engaged in transportation are not subjected to the same hazard as those engaged in the preparation of shipments, and therefore the limit of 200 milliroentgens per hour at the surface of the package, and the limit of 10 milliroentgens per hour at a distance of one meter from the package, are reasonable even though they may be higher than could be tolerated as far as the actual operation of preparing shipments is concerned.

We must remember that the tolerances I have just stated are maximum, and there is nothing to prevent any shipper from so shielding his product that the radiation outside the package is lower than required by the regulations.

Dealing with the other hazard in transportation, namely the hazard to other property, our prime concern is the possibility of damage to unexposed or undeveloped film, and particularly the more sensitive films such as X-ray types, which become useless if any degree of fogging has occurred. You will agree that it would not be reasonable to ask film

manufacturers to shield their shipments against the effects of radiation, although they do so to a small degree, because to do so would result in a needless waste of material. There are many shipments of film which never even come close to shipments of radioactive materials, and probably in the majority of instances any shielding precautions would be needless.

It is therefore necessary to so prepare shipments of radioactive materials that, provided reasonable precautions are observed, film will not be damaged because of their presence in vehicles or stations.

The entire responsibility for protecting shipments of film from damage has not been placed upon the shipper, and it was to adequately and reasonably protect such shipments that we have provided for only certain quantities of radioactive material to be shipped in any one car or vehicle, or stored in any one location, while in transportation, and that packages of undeveloped film must be kept at certain specified distances from shipments of radioactive materials. Here again, we have tried to be as reasonable as possible, and from the record and number of complaints received it would appear that we have handled the matter properly.

Most of what has been said heretofore applies specifically to the large number of small shipments which are moving daily in transportation. Shipments consisting of large quantities of radioactive materials must, under the regulations, be in containers approved by the Bureau of Explosives. While I do not presently see any hope of entirely eliminating the need for such approvals, if for no other reason than that there is still much development work to be done which will require special types, sizes, and shapes of containers, the regulations do need to be amended regularly to provide for larger quantity shipments than are presently authorized. A few years ago a step was made in this direction when provision was made for shipping four isotopes, which are common items of commerce in I.C.C. Spec. 55 containers. I believe that the time has long since arrived when we should have a provision in the regulations to permit quantities as high as 5,000 curies of material in standard types of containers with certain details of construction which would be made part of a specification. The problem of containers for these larger sources has been considered by many groups and much scientific thought has been given to the design of containers. Some of this, I believe, can be properly criticized for the simple reason that it presupposes fire conditions which rarely, if ever, occur in transportation or else assumes impacts which are the exception rather than the rule. The odd part of all this is that it accomplishes nothing which has not already been well established by experience. Accidents in rail transportation and highway transportation are not new to us nor is the subject of container design. When we had to consider containers for the dangerous forms of radioactive materials, we suggested methods of manufacture which experience with tank cars, compressed cylinders, and other containers

(Text continued on page 54.)

BUREAU OF EXPLOSIVES
AND
FREIGHT LOADING AND CONTAINER SECTION
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T. C. GEORGE, DIRECTOR AND CHIEF INSPECTOR

FILE NUMBER 25-16-174

PERMITS - RADIOACTIVE MATERIALS

Bureau of Explosives Permits may be issued to cover shipments and containers under the provisions of sections 73.391 and 73.393(f) of the Interstate Commerce Commission Regulations. The following details must be complied with if the quantity of radioactive material to be shipped exceeds that normally authorized in section 73.391 or 73.393. In other cases the container must be at least as efficient as those authorized in the Regulations. Details of the container must be submitted and permit obtained prior to shipment.

1. Lead shield or other shielding material of equal efficiency must be encased in steel or other suitable material so that shielding will not flow away or lose its efficiency if involved in a fire. Steel or other suitable material must be at least 1/8" thick for 6 inches or less of lead or other shielding and 1/4" thick for more than 6 inches of shielding.

(a) Casing thickness shall be determined by the thickness of shielding measured from cavity wall to nearest point of outside container.

2. Shield must be supported in outer container so that it cannot change position or open under any ordinary conditions.

3. Parts of shield must be so designed that radiation cannot be "beamed" at point where container sections join (i.e. offset design required).

4. Radiation at any surface of package must not exceed 200 mrh and radiation at one meter from radioactive source of package must not exceed 10 mrh.

5. Container must be designed so that it can be properly braced in car.

6. Containers weighing more than 500 pounds must be fitted with skids or otherwise designed so as not to create excessive pressure on small areas of the car or truck floor and must be marked with gross weight if for water transportation.

7. Heavy containers to be provided with hooks, handles, and skids, or any other device necessary to facilitate normal handling.

8. Outer container, when practicable, must be of metal with joints 100% welded or brazed and closure must be secured by positive fastening device capable of withstanding severe impacts without failure.

(a) Shielding material, if any, in closure part must be completely encased in metal with joints 100% welded or brazed.

(b) It is required that all specification 55, and other radioactive material shipping containers approved by the Bureau of Explosives, constructed with tubing for drainage purpose, have the opening exterior to the shipping container plugged or capped. Drain lines must be plugged or capped with a material which will have a melting point at or below that of lead, for example, lead, hard rubber or plastic.

9. Means must be provided for applying a seal so that outer container cannot be opened without destroying the seal.

10. Containers for more than 4,000 millicuries or the radioactive equivalent must have name "Radioactive Material" and permit number stamped, embossed or otherwise permanently applied so that it will not be obliterated by fire.

11. Approval of shipping containers for materials where criticality must be considered will be on basis of design and product data furnished.

12. Each time a shipment is made in excess of that quantity permitted in container by section 73.391 or 73.393 of the Interstate Commerce Commission Regulations, it shall be necessary to notify the Bureau of Explosives, unless otherwise stated in the permit, by letter, telegram or telephone on or before date of shipment, furnishing the following information:

(a) Assigned B.E. Permit Number or ICC Specification Number marked on outer shipping container.

(b) Assigned B.E. Block Transportation Number used, if any has been assigned.

(c) Point of origin, destination and date shipment is to be made.

(d) Type of transportation used.

(e) Quantity of radioactive material in terms of curies, millicuries, or disintegrations per second and the principal type of radiation (Alpha, Beta, Gamma, or Neutron).

Revised 3/22/62

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FILE NUMBER 25-16-174

PERMITS - SPENT (Irradiated) FUEL ELEMENTS

Methods for packaging and shipment of spent fuel elements must be submitted to the Bureau of Explosives for approval. Minimum container requirements are as follows:

A. Spent fuel elements after removal from reactors should be stored for a period necessary to allow for cooling by decay until temperature is reached so that after the elements are placed in shipping containers no problem from heat dissipation will exist in transportation, except as stated in subparagraphs (1), (2), (3), and (5) herein.

(1) If the container is provided with a cooling system, the system must be so designed that probability of loss of coolant would be remote even in event of an accident. Any part of the cooling system external to the shipping container must be well protected to prevent damage by impact or vibration. Where water is used as a cooling medium, the container must be equipped with expansion tanks and pressure relief vents.

(2) When mechanical apparatus is necessary to maintain cooling, an auxiliary unit must be furnished so that there will be no interruption in the cooling system should one unit fail. Escorts must accompany systems employing mechanical cooling apparatus.

(3) When liquid coolant is used in containers, provisions shall be made to prevent freezing of the coolant or sufficient outage must be provided so that container will not be ruptured or damaged and coolants and anti-freeze must be of a safe type.

(4) The external temperature at any readily accessible surface of the shipping container shall not exceed 180° Fahr.

(5) Shipping containers employing liquid coolant during transportation must be capable of maintaining their shielding efficiency and mechanical integrity for a period of at least 48 hours should the coolant be lost for any reason.

B. The following are minimum container construction requirements:

(1) Lead shield, or other shielding material of equal efficiency, must be encased in steel or other suitable material so that shielding will not flow away or lose its efficiency if involved in a fire. Steel, or other suitable material, must be at least 1/8" thick for 6" of lead or other shiedling or less, and 1/4" thick for more than 6" of shielding.

(a) Casing thickness shall be determined by the thickness of shielding, measured from cavity wall to nearest point of outside container.

(2) Shield must be supported in outer container so that it cannot change position or open under any ordinary conditions, and must be capable of maintaining its efficiency under severe fire conditions.

(3) Parts of shield must be so designed that radiation cannot be "beamed" at point where container sections join (i.e. offset design required).

(4) Radiation at any surface of package must not exceed 200 mrh and radiation at one meter from radioactive source must not exceed 10 mrh.

(5) Container must be designed so that it can be properly braced in car or truck.

(6) Containers must be fitted with skids or otherwise designed so as not to create excessive pressure on small areas of supporting structures, such as decks of ships or vehicle floors, and must be plainly marked with gross weight if for transportation by water.

(7) Heavy containers must be provided with hooks, handles, trunions, and skids, or any other device necessary to facilitate normal handling.

(8) Container for the lead shielding must be of metal with welded joints and closure must be secured by positive fastening device capable of withstanding severe impacts without failure - see note (a).

(a) Shielding material, if any, in closure part must be completely encased in metal with welded joints.

(9) Except for containers requiring special equipment to open, means must be provided for applying a seal so that outer container cannot be opened without destroying seal.

(10) Containers must have name RADIOACTIVE MATERIAL and permit number stamped, embossed, or otherwise permanently applied so that they will not be obliterated by fire.

C. The complete shipping container having spent fuel elements must be designed and maintained so as to provide against criticality in the presence of other shipping containers of fissionable materials during transportation.

Oct. 30, 1959

has already established as providing a very high degree of safety within practical limits. In all of the work I have seen come out of committees considering the subject, I have not yet seen the suggestion that containers whenever practicable be cylindrical in shape as they would be more liable to repel or roll away from forces to which they were subjected under accidental conditions. Until someone tells me something better, I shall continue to promote this idea, although the Bureau will not refuse to approve other shapes when design conditions make the use of other shapes necessary. If a general purpose standard container can be adopted, I feel that one requirement of the specification should be that the container be cylindrical in shape. Time does not permit me to go over the details of construction, which we require in approving containers, but I do have mimeograph sheets outlining those requirements available to those who wish them.

In concluding, I should like to leave one thought with you which should be considered above all others "An impractical regulation will never prevent an accident".

Session Chairman:
Mr. Lester Rogers is well known to all of you. In addition to his AEC hat, Mr. Rogers wears the hat as Chairman of the Interagency Committee of Federal Agencies on Transportation and, wearing both of those hats, has acted as our representative to the IAEA and the various foreign governments who have worked with us.

INTERAGENCY COMMITTEE WORK ON U. S. TRANSPORTATION REGULATIONS APPLICABLE TO RADIOACTIVE MATERIALS

by

Lester R. Rogers
Division of Licensing and Regulation
U. S. Atomic Energy Commission

INTRODUCTION

In late 1957 the Interagency Committee on Transportation of Radioactive Materials was formed as a working Committee to provide a forum for coordinating the activities of the Federal Agencies having responsibility for regulating safety in the transport of radioactive materials in the developing of new regulations and revisions of existing regulations dealing with safety in the transportation of radioactive materials. The Committee is composed of representatives of the Interstate Commerce Commission, Federal Aviation Agency, U. S. Coast Guard, U. S. Post Office Department, Atomic Energy Commission and the Bureau of Explosives of the Association of American Railroads. During the past two years the Committee has been working on comprehensive revisions to federal transportation regulations applicable to radioactive materials. The purpose of this paper is to review the status of this work. However, I will first present background information which is pertinent to the work of the Committee and which serves as a basis for the Committee's actions.

RESPONSIBILITY FOR REGULATIONS

The responsibility for regulating safety in the shipment of radioactive materials in the United States rests with five different agencies at the Federal level. In addition, there are numerous state and local agencies and bridge, tunnel, turnpike and port authorities who have a responsibility for safety of radioactive shipments moving on or through their transportation facilities.

At the Federal level the Interstate Commerce Commission regulates the transportation of dangerous articles, including radioactive materials, moving in interstate and foreign commerce within the United States by land or water, such as rail freight,

rail express and commercial motor vehicles. The U. S. Coast Guard regulates the handling and stowage of radioactive materials aboard ship for water transportation. The Federal Aviation Agency regulates the movement of radioactive materials by air. The U. S. Post Office Department regulates the shipment of radioactive materials through the mails. The Atomic Energy Commission has broad authority under the Atomic Energy Act of 1954, as amended, to regulate the possession, use, transfer and disposal of source, special nuclear and byproduct materials.

REGULATIONS NOW IN FORCE

Each of the five federal agencies mentioned above have published regulations governing safety in the transport of radioactive materials. The present ICC regulations were developed in 1947 and published in Code of Federal Regulations, Title 49, Parts 71-78 in January 1948. They are also published in Agent T. C. George's Tariff No. 13, Bureau of Explosives, a document which should be thoroughly familiar to all shippers of radioactive materials. The regulations limit the quantities of radioactive material that can be shipped in a single package without special ICC approval to not more than 2 curies of radium, polonium or other members of the radium family of elements, and not more than 2.7 curies of any other radioactive material except solid cesium 137, cobalt 60, gold 198, or iridium 192 for which the quantity is 300 curies. Quantities in excess of the above limits may be shipped only by special arrangements and under conditions approved by the Bureau of Explosives. The regulations set forth packaging specifications, including requirements for outside containers and special requirements for internal containers for highly toxic radioactive materials and materials in liquid form. Shielding specifications are set forth to limit the radiation levels external to the container to specified values. Packaging labeling and vehicle placarding requirements are also specified.

The Federal Aviation Agency and Coast Guard regulations closely follow the requirements of ICC regulations with respect to packaging and labeling with additional provisions on stowage which are peculiar to the mode of transportation. FAA regulations are published in Code of Federal Regulations under Title 14, Part 49. Coast Guard regulations are published under Title 46, Part 146.

The Post Office Department regulations published in Part 1 of the U. S. Postal Guide, Article 37, Chapter IV, prohibit the use of the mails for transporting radioactive materials except for specified small quantities and items that are exempt from ICC packaging and labeling requirements.

The AEC has issued regulations applicable to AEC licensees governing the shipment of special nuclear material, 10 CFR Part 71, and has issued a proposed regulation governing the shipment of irradiated fuel elements, 10 CFR Part 72. The AEC has exempted common and contract carriers and the U. S. Post Office Department from its licensing regulations, 10 CFR Parts 30, 40 and 70 to the extent that they transport or store source, special nuclear or byproduct material

in the regular course of carriage for another or storage incident thereto.

The Division of Radiation Protection Standards recently requested 61 members of the American Bridge, Tunnel and Turnpike Association to provide information on transportation regulations applicable to their facilities. Forty-seven members have responded to the request. The survey revealed that 32 out of the 47 have issued no specific regulations. Eleven out of the 47 have adopted ICC regulations or a modification of ICC regulations and 3 out of the 47 prohibit the transport of radioactive materials over their facilities. This survey does not cover all state and local groups having responsibility for transport regulations but it is indicative of the complexities involved in achieving compatible regulations governing safety in the movement of radioactive materials throughout the United States.

OBJECTIVES OF INTERAGENCY COMMITTEE REVISION

The safety experience to date in moving hundreds of thousands of shipments of radioactive material during the past fifteen years under present regulations is excellent and has been reviewed in detail by Mr. Patterson. In view of this safety record one might well question why present radioactive materials transportation regulations should be changed. However, the types, forms and quantities of radioactive materials that must be moved are continually changing. The number of special approvals by the regulatory agencies required by present quantity limitations are growing and can become burdensome on shippers and regulatory agencies alike. The regulations must, therefore, be continually reviewed and revised to deal with the changing problems of transport of radioactive materials in a growing atomic energy industry.

In undertaking a comprehensive revision of existing federal transportation regulations applicable to radioactive materials in 1959 the Interagency Committee had the following principal objectives in mind:

1. To provide a more practical working form of the regulations which can be referenced with ease, a separate subpart should be established in ICC regulations for radioactive materials. At present, radioactive materials are listed in a section under subpart G - Poisonous Articles, as a Class D poison.

2. The need for special approvals should be minimized. The quantity limitations for packages for routine shipment should be substantially raised when this can be done without compromising health and safety.

3. A more definitive classification of shipments relating potential hazard with type and quantity of material, packaging requirements, labeling and placarding requirements and administrative procedures should be developed. The Bridge, Tunnel and Turnpike authorities have insisted on such a classification so that they might

be able to differentiate between those shipments that should move routinely over their facilities and those that require special approval. Present regulations do not differentiate by label or placard between low, medium and high level shipments. As a result of the inability to differentiate between categories of shipments some of the toll facilities have prohibited transport of radioactive materials over their facilities. To quote Mr. Roy Gibson of the United Kingdom Authority Health and Safety Branch, "We can no longer expect competent authorities, port authorities and others to be content that a shipment is safe because we in the industry are satisfied that it is safe - safety not only has to be achieved but must be seen to be achieved."

4. To the extent possible the Committee should strive toward contributing to consistency with international transport regulations. However, it was recognized that there may be shipping problems peculiar to the United States which may dictate some departure from international regulations.

5. More specific recognition should be given in the regulations to problems of criticality safety in the shipment of special nuclear or fissile material.

IAEA REGULATIONS

At about the same time in 1959 that the Interagency Committee initiated serious consideration of a comprehensive revision of U. S. regulations, the International Atomic Energy Agency convened two panels in April and July 1959 to develop transport regulations for the Agency. These were Panel I on the Transport of Radioisotopes and Radioactive Ores and Residues of Low Specific Activity and Panel II on Transport of Large Radioactive Sources and Fissile Materials. Two members of the Interagency Committee participated on the IAEA panels. Mr. V. E. Haninger of the ICC participated on Panel I and the author of this paper participated on Panel II. The panels drew heavily on the concepts contained in present ICC regulations which were developed in 1947 and 1948. This is a tribute to the soundness of the concepts developed by the authors of ICC regulations. The regulations also incorporated new concepts developed by the Panels which reflected experience during the past 15 years in thousands of shipments of radioactive material in national and international transport. The regulations developed by the Panels were combined by the IAEA and issued in IAEA Safety Series No. 6 in May 1961.

The Interagency Committee took full advantage of the work of the IAEA panels and agreed to use the IAEA regulations as a basis of revision of U. S. regulations. It found that they provide the basis for accomplishing most of the objectives the Committee had outlined. It was found necessary, however, to adopt several variations from IAEA regulations because of practical problems based on experience by shippers of radioactive materials in the U. S. We intend to submit recommendations to the IAEA that some of these variations be considered by a panel that is meeting in March 1963 for incorporation in IAEA regulations.

The Committee developed a Draft Technical Standard based on the IAEA regulations to be used as a basis for preparation of regulations for the safe transport of radioactive materials. This document was widely circulated in late 1961 to the transport industry, nuclear industry, state and local groups and other interested parties for comment. Many constructive comments on the document were received by the Committee.

During the past nine months the Committee has reviewed the comments, revised the Draft Technical Standards and incorporated the revised technical standards into a proposed revision of ICC regulations. It is the intent of the Committee to submit the proposed revision to the ICC for consideration as a basis for revision of ICC regulations in accordance with the ICC rule-making procedure.

The revision of ICC regulations will then serve as a basis for similar revisions of other federal transportation regulations. It will also serve as a model for State and Local groups having a responsibility in this area. The Interagency Committee has agreed to assist the Council of State Governments in drafting a model transportation regulation that can be recommended to interested state and local groups as soon as work is completed on the ICC regulation.

INTERAGENCY COMMITTEE PROPOSED MAJOR CHANGES IN ICC REGULATIONS

A detailed comparison of the provisions of present ICC regulations, Interagency Committee proposed revisions of ICC regulations, and IAEA regulations is given in Appendix B, attached. Some of the major Interagency Committee proposed changes in present ICC regulations are as follows:

1. A separate subpart for radioactive materials would be established in ICC regulations. Radioactive Materials would no longer be listed as a Class D Poison under subpart G.

2. Quantity limits per package that could be shipped without special approval by the regulatory agency would be substantially increased and would be based on the three group radiotoxicity classification developed by IAEA. The quantities would be related to toxicity and type of package in which they are shipped. The quantities which could be shipped without special approval by the regulatory agency would be increased from 2.7 curies to 20 curies for Group I and II, 200 curies for Group III, 3000 curies of tritium or krypton 85, from 300 curies of solid cobalt 60, cesium 137 and iridium 192 to 5000 curies for special forms, such as encapsulated solids.

3. The quantities of radioactive material exempt from ICC regulations would be lowered for the highly toxic radioactive materials and increased for some of the less toxic radioactive materials. For radionuclides such as radium 226 and plutonium 239 (Group I) the quantity would be changed from 100 microcuries to 10 microcuries. For Group II materials the limit would remain at 100 microcuries and for Group III materials the limit would be

1 millicurie. Up to 10 millicuries of tritium and krypton 85 would be exempt.

4. Exemptions for instruments, clocks, electronic tubes or similar manufactured goods of which the radioactive material is in a non-readily dispersable form, would be expanded and would more clearly define the quantity limits in such devices.

5. A section would be added dealing specifically with the shipment of fissile materials. This section would define quantities which are exempt from special approval with respect to criticality safety. ICC regulatory requirements would refer to the requirements of AEC regulations with respect to criticality safety. ICC regulations would also establish the 40 unit rule to be applicable to the shipment of fissile materials.

6. Specific contamination limits applicable to the exterior of packages, cleaning of cars and motor vehicles, and shipping empty packages would be included.

7. The labeling and placarding requirements would be substantially modified. The present blue wording on white background label for packages of material emitting only electrically charged corpuscular radiation or with radiation levels not exceeding 10 mr in any 24 hours would be replaced by a white background label with black printing. The present red printing on white background label for packages with radiation levels in excess of 10 mr in any 24 hours would be replaced with a yellow background label with black printing. These two labels would be used under the conditions specified for quantities of radioactive material in each one of the three groups which can be shipped without special approval by the regulatory agency. (i. e., Group I & II, 20 curies; Group III 200 curies; special form 5000 curies; tritium and krypton 3000 curies.) A red label would be required on all packages containing quantities of radioactive materials which require special approval by the regulatory agency. A special label would be provided for radioactive materials of low specific activity such as magnesium-thorium alloys. The label would indicate that the package presents no radiation hazard to personnel in transportation. An "empty" label would be added to be used on packages that are being transported empty but have internal fixed contamination above specified limits.

The present "Dangerous, Radioactive Materials" placard which is required on all rail shipments of radioactive material and on all Group I & II truck shipments, would be replaced with two placards. A yellow placard with the word "Radioactive" with additional explanatory information would be required on vehicles carrying packages with quantities which do not require special approval by the regulatory agency. A red placard with the word "Radioactive" and additional explanatory information would be required for vehicles transporting packages of radioactive material which contain quantities that require special approval by the regulatory agency. The objective of the change in labeling and placarding is to provide a categorization of radioactive material shipments to simplify the administrative control

requirements of bridge, tunnel, turnpike, port and other authorities who are charged with the responsibility of authorizing the movement of radioactive materials through their facilities. Attached as Appendix A is an explanation of the categorization provided in the proposed revision of ICC regulations. Under this categorization it would be expected that all materials in Categories I, II and III would move routinely throughout the United States without special approval. Movements of Category IV shipments, red placard, would require special approval of the regulatory agency and in some cases local bridge, tunnel, turnpike and port authorities.

8. The point of measurement of the external dose limit (i. e., 10 milliroentgens per hour at one meter) would be changed from one meter from any point on the radioactive source to one meter at any point on the surface of the package.

MODIFICATIONS OF IAEA PROVISIONS

The Interagency Committee proposed revision of ICC regulations is based on IAEA regulations as published in Safety Series #6. While it has been necessary to make some modifications based upon practical shipping experience in the United States it is believed that the Committee revision is compatible with the objectives of the IAEA regulations. The principal areas where modifications of IAEA provisions were deemed necessary are as follows:

1. IAEA regulations provided no exemption from the provision of the regulations for Group I materials. The proposed Interagency Committee revision would exempt up to 10 microcuries of Group I material, 10 millicuries of tritium and krypton 85 would be exempt whereas the IAEA regulations would limit these quantities to 1 millicurie under Group III.

2. The definition of "non-friable, massive solid" has been expanded to include encapsulated sources and to more clearly define the chemical and physical characteristics of material falling in this category. The quantity limits of 20 curies for Type A packaging has been retained in the revision of ICC regulations but the quantity limit for Type B packages has been increased for this category to 5000 curies. This limit was raised after a careful evaluation of the number of shipments currently taking place within the U. S. demonstrated the need for increasing this limit to eliminate the need for a number of special approvals. This change agrees with the thought expressed in the "Notes on Certain Aspects of the Regulations," IAEA Safety Series #7, that the large radioactive source limits were established in large measure on the basis of need.

3. A specific exemption for uranium and thorium ores during transfer from the mine to the first point of processing has been included in the Committee revision. The definition of radioactive materials in IAEA regulations does not include materials whose radioactivity is less than 0.002 microcurie per gram. While this excludes most uranium and thorium ores there may be some rich deposits which will exceed 0.002 microcurie per gram of ore as mined.

4. Quantity limits have been placed on the exemptions for manufactured items given in IAEA regulations. While it is unlikely that the items exempted would contain substantial quantities of radioactive material it was considered that some upper limit should be placed on the quantity per device which is exempt.

5. The limitation on IAEA regulations that no more than 50 packages shall be loaded aboard one vehicle has been eliminated from the proposed Committee revision. This restriction would seriously inhibit the transport of radioactive materials in the U. S. and we believe it unnecessary. In a recent survey we determined that current shipments indicate that the curie content of most packages of Type A are far below that permitted in a Type A package. The survey also indicates that in most cases more than 50 Type A packages are transported within the 40 unit limit and would contain very much less than 50 times the Type A packaging limit. We believe that it is not necessary to place a limit on the total number of packages aboard one vehicle but that practical shipping needs will limit the total quantity of material aboard a vehicle to satisfactory limits.

6. The skull and crossbones and the number 7 have been deleted from the IAEA label and placard for use in proposed U. S. regulations. Because of the administrative problems on the movement of radioactive materials over bridge,tunnel, turnpike and port facilities a third label and placard with a red background has been included in the proposed revision of ICC regulations to be used on all packages and shipments requiring special approval by the regulatory agency.

7. Many shipments within the U. S. involve irradiated samples or samples of material separated from irradiated nuclear fuel containing a mixture of fission products. Therefore, an item has been added to the Group II classification to be identified only as mixed fission products.

The above constitutes the principal modifications of IAEA provisions in the proposed Interagency Committee revision of ICC regulations. We have informed the IAEA of these modifications and have recommended that they be considered as a basis for modification of IAEA regulations by the Panel which the IAEA is convening in March to consider amendments to their regulations.

Appendix "A"

CATEGORIZATION OF RADIOACTIVE MATERIALS SHIPMENTS

The Interagency Committee on Transportation of Radioactive Materials has developed Technical Standards to be used as a basis for transportation regulations. The Standards contain a four-part categorization of radioactive material as related to their potential hazard under accidental conditions in transport. Within the

categorization, radioisotopes are divided into three groups according to their radiotoxicity.

Group I ---------- Very high radiotoxicity
Group II ---------- High radiotoxicity
Group III ---------- Moderate or low radiotoxicity

Packaging and shipping requirements are divided into four categories. Quantity limitations, packaging requirements and shipping procedures for each category are related to the three radiotoxicity groups referred to above. Attached is a diagram depicting these four categories.

The first category includes types and quantities of material that, because of their very low hazard potential, are exempt from packaging and labeling requirements under specified conditions of shipment and can be shipped without special approval of the regulatory authority. This category includes very small quantities of material in each radiotoxicity classification, and manufactured articles such as luminous dials of which radioactive materials are a component part. It also includes low activity materials such as uranium ores and concentrates and low activity wastes in truckload or carload lots. The truck or car must carry a yellow placard.

A second category includes types and quantities of materials in each radiotoxicity classification that are of a low to moderate hazard if released from a package but which requires specification packaging and labeling in a Type A package. Such a package must be designed to withstand normal handling and minor accidents incident to transportation without loss of material but may rupture in a serious accident under severe impact forces or fires. The quantities of material that may be transported in such packages are such that it is unlikely that any individual will ingest, inhale or absorb quantities of material to present a serious health hazard in the event of accidental release from the package. Rail cars and motor vehicles are required to carry a yellow placard.

A third category includes types and quantities of material in each radiotoxicity grouping that would, if accidentally released from a package, present a substantial hazard from the standpoint of exposure of individuals and contamination of property, but which can move routinely in transport without special approval provided the package is designed to contain the material and retain its shielding properties in the most severe accident considered credible for the mode of transport used, including severe impacts and gasoline fires. Such a package is designated a Type B package and requires specification labeling. Rail cars and motor vehicles are required to carry a yellow placard.

A fourth category consists of types and quantities of material in each radiotoxicity classification that, if released from a package, may present a high degree of hazard to the public and serious

contamination of property. Such materials are required to be shipped only in Type B containers after special approval by the regulatory authority. Administrative requirements relating to routing, notifications, special precautions, etc., are determined for each individual shipment and required by the regulatory authority under the special approval. All packages in this category require a red label and rail cars or motor vehicles must carry a red placard. Special instructions as to handling precautions accompany each motor vehicle or rail car.

Category four also includes fissile materials or special nuclear materials. Since these materials present a potential hazard from accidental criticality, AEC approval is required for the shipment of all but very small quantities of these materials containing uranium 235, plutonium or uranium 233.

It is to be noted that the classification as related to radiotoxicity and the four categories are based primarily on limiting the potential hazard to individuals in the vicinity of an accident in the event radioactive material is released from the package. The effort and expense involved in decontamination of property may vary widely depending upon circumstances surrounding the accident. However, since limitations are placed on quantities permitted to be shipped in a single package in each category, the risk to property is also limited. The potential risk to property is further reduced by requiring that substantial quantities of material be shipped in a Type B package.

The Draft Technical Standards relate packaging requirements to the radiotoxicity classifications, quantity limitations and potential hazard from material if released from the package.

The Type A package must be leakproof, securely closed by a positive fastening device, shielded adequately to prevent an external dose rate in excess of the values prescribed in the regulations and must prevent loss or dispersal of the radioactive contents and retain shielding efficiency under conditions normally incident to transport (such as minor drops and spills) and under minor accident conditions. Quantities of material that may be shipped in a Type A package are limited so that the degree of hazard to workers or the public is reasonably low even if the container ruptures and releases its contents.

The Type B package must be designed so as to maintain its integrity under conditions normally incident to transport without loss or dispersal of the radioactive contents and the package must retain shielding efficiency under conditions normally incident to transport and in the most severe accident which is considered credible for the mode of transport involved.

APPENDIX A

CATEGORIZATION OF SHIPMENTS OF RADIOACTIVE MATERIALS

Category 1				Category 2				Category 3				Category 4
Exempt (from packaging and labeling)				Low to Moderate Hazard				Requires Special Packaging				Large Radioactive Sources and Fissile Material[a] Requires Special Approval
Radiotoxicity Group			10 mcs tritium and krypton	Radiotoxicity Group			Confined Source	Tritium & Krypton	Radiotoxicity Group			Confined Source	Tritium & Krypton	
I	II	III		I	II	III			I	II	III			
Not more than 10 µcs	100 µcs	1000 µcs	Mfgd. Goods, Low Activity Materials & Wastes	0.1 mc	10 mcs	2 C	20 C	50 C	20 C	20 C	200 C	5000 C	3000 C	Any Quantity Greater Than That Permitted in Preceding Categories and Fissile Materials
TYPE OF PACKAGE REQUIRED FOR TRANSPORT														
Exempt from Requirements Under Specified Conditions				Type A					Type B					Type B or as approved for Fissile Materials
LABELING OF PACKAGES														
Non-required				White or Yellow					White or Yellow					Red
PLACARDING OF VEHICLES														
Yellow Placard for Low Activity Materials and Wastes only in truckload lots				Yellow placard					Yellow placard					Notice and special instructions in driver's compartment and red placard

µc - microcuries
mc - millicuries
c - curies

a/ Fissile materials or special nuclear materials in this category include any shipment which contains in excess of 1.0 µc of plutonium 239, 10.0 µcs of plutonium 241, 1.0 mc of uranium 233 or 16 grams of uranium 235.

APPENDIX B

A COMPARISON OF THE SUBSTANTIVE REQUIREMENTS OF THE
PRESENT ICC REGULATIONS, THE INTERAGENCY COMMITTEE PROPOSED REVISION OF ICC REGULATIONS, AND THE IAEA REGULATIONS

	PRESENT ICC	PROPOSED ICC	IAEA
DEFINITIONS RADIOACTIVE MATERIALS	Radioactive material is any material or combination of materials that spontaneously emit ionizing radiation. (73.391(a))	Any material or combination of materials in any form that spontaneously emits ionizing radiation and in which the radioactivity per gram is greater than .002 microcurie. (73.391(a))	Any material which spontaneously emits ionizing radiation and of which the radioactivity per gram is greater than 0.002 microcurie. (1.1.6.)
RADIATION UNIT	is one milliroentgen per hour at one meter for "hard gamma" radiation or that amount of radiation which has the same effect on photographic film as one milliroentgen per hour at one meter of "hard gamma" rays of radium filtered by 1.27 centimeters (0.5 inch) of lead. (75.655(j)(2))	One radiation unit [3/] shall be the following: (1) The radiation dose rate measured at one meter (39.3 inches) from the external surface of the prescribed or approved package equal to: (i) One milliroentgen per hour of X and gamma radiation; (ii) One millirad per hour of beta radiation which is the equivalent of one milliroentgen per hour; (iii) The equivalent of one milliroentgen per hour for the neutron flux according to the following table; (The table is substantially the same as IAEA Table IX.)	The total of the following dose rates measured at 1 meter from the external surface of a package at the place where the value is the highest, shall be called the number of radiation units for this package: (i) for gamma- and/or X-radiation of energy greater than 200 keV: the number of milliroentgens per hour. (ii) for gamma- and/or X-radiation of which more than 20% has an energy less than 200 keV: the number of milliroentgens per hour multiplied by 3/2. (iii) for beta-radiation: the number of milliroentgens per hour which is equivalent. (iv) for neutrons: the number of radiation units, according to the flux relationship given in Table IX, Annex I. (1.1.5.)

	PRESENT ICC	PROPOSED ICC	IAEA
RADIATION UNIT (cont'd)		(2) For fissile material shipments, a number determined on the basis of the allowable number of packages in a shipment in accordance with paragraph 73.396(e). 3/ In measuring the radiation dose rate to determine the number of units, an instrument shall be used except that neutron radiations may be determined by calculations or measurements. (73.391(c))	
FISSILE MATERIALS	No equivalent.	Fissile materials 2/ shall mean plutonium 239, plutonium 241, uranium 233, uranium 235, and any material artificially enriched in any of the foregoing. 2/ Fissile materials do not include natural thorium and natural or depleted uranium. Fissile materials are also referred to as "Special Nuclear Materials." (73.391(b))	Pu 239, Pu 241, U 233, U 235, or any material containing any of the foregoing that falls within the definition of radioactive materials. (1.1.2)
CLASSIFICATION OF MATERIALS	Materials divided into three groups according to the type of radiation emitted at any time during transportation: Group I: emitting gamma radiation alone or with electrically charged particles or corpuscles;	Radioactive materials classed into four groups (first three groups same as IAEA) as follows: Group I: Very High Radiotoxicity and any unidentified or unknown radioactive material.	Radioisotopes divided into three groups according to radiotoxicity: Group I: Very High Radiotoxicity Group II: High Radiotoxicity Group III: Moderate or Low Radiotoxicity Isotopes listed alphabetically in Table IV, Annex I.

	PRESENT ICC	PROPOSED ICC	IAEA
CLASSIFICATION OF MATERIALS (cont'd)	Group II: emitting neutrons and either or both types characteristic of Group I materials; and Group III: emitting only electrically charged corpuscular rays or any other material shielded so that gamma radiation at surface does not exceed 10 mr/24 hrs at any time during transportation. (73.391(a))	Group II: High Radiotoxicity Group III: Moderate or low radiotoxicity Group IV: Special Forms (i) The following radionuclides: Krypton 85 Tritium (Hydrogen 3) and (ii) any radioactive material provided either the material or the capsule in which it is enclosed is capable of complying with each of the following conditions: (1) It has no dimension less than 0.2 inch except in the case of needles, wire foil or thin strips having a volume of at least 0.0015 cubic inch; (2) It does not melt or sublimate below 1000° F; (3) It cannot be ignited and will not release radioactive material when exposed to a temperature of 1700° F for one hour;	Any isotope not listed to be treated as Group I. (6.1.)

	PRESENT ICC	PROPOSED ICC	IAEA
CLASSIFICATION OF MATERIALS (cont'd)		(4) It will not break or shatter or lose radioactive material under a blow of 10 ft-lbs between a steel hammer and a soft pine block; (5) After one week's immersion in water at pH8 at 70° F, it has not dissolved or converted into reaction products at the rate of more than 5 parts per million for materials consisting wholly or in part of isotopes of toxicity Group I, or 500 parts per million for material consisting wholly of isotopes in other toxicity groups or the capsule is shown to be leak-free; and (6) After one week's exposure to air at 90° F, it has not converted into reaction products at the rate of more than 5 parts per million for material consisting wholly or in part of isotopes of toxicity Group I, or 500 parts per million for material consisting wholly of isotopes in other toxicity groups. Note 1/ The radioactive materials have been classed into the groups according to the dose to the critical organ which could result from the intake of one microcurie of either the soluble or the insoluble form of the radionuclide whichever is the greater dose and based on biological data prepared by the International Commission on Radiological Protection (Report of Committee II on Permissible Dose for Internal Radiation (1959)). (73.391(a))	

	PRESENT ICC	PROPOSED ICC	IAEA
EXEMPTIONS SMALL QUANTITIES	Materials are exempt from the classification, packaging and labelling requirements for radioactive materials provided the package: (i) does not contain more than 0.1 mc of Ra or Po, or 0.135 mc of Sr 89, Sr 90, Ba 140, or 1.35 mc of any other radioactive material; (ii) constructed to prevent leakage in normal transport conditions; and (iii) shielded so that no significant emission of alpha, beta or neutron radiation nor more than 10 mr/24 hrs of gamma. (73.392(a))	Limits 10 uc of Group I materials, 0.1 mc of Group II materials, 1.0 mc of Group III materials, 10. mc of Hydrogen 3 or Krypton 85, 10. uc of Pu239, 0.1 mc of Pu 241, 1. mc of U 233, or 16 gm of U 235 Conditions Surface radiation level must not exceed 0.4 mr/hr. There must be no leakage from the package under conditions incident to transport. For packages shipped via water carriers, the name of the contents must be marked on the outside surface. For fissile materials the smallest external dimension shall not be less than 4 inches. (73.392(a))	Limits No quantity of Group I materials is exempt except for instruments and empty packages, 0.1 mc of Group II materials, 1.0 mc of Group III materials, 9 gm of Pu, 16 gm of U 233, or U 235 or proportionate mixtures of the fissile materials. Conditions Surface radiation level must not exceed 10 mr/24 hrs. Non-fixed surface contamination must be below levels specified in Table X. There must be no leakage from the package under conditions normally incident to transport. For fissile materials the smallest external dimension shall not be less than 4 inches. (13.2 and 6.2.2)
INSTRUMENTS, etc.	Similarly exempted are: Manufactured articles, other than liquids, such as instrument or clock dials of which radioactive materials are a component part, and luminous compounds when securely packed in strong outside containers with surface radiation less than 10 mr/24 hrs. (73.392(b))	Manufactured articles other than liquids, such as instruments, luminous compounds, clocks, clock dials, electronic tubes or apparatus, or similar manufactured products of which radioactive material in a non-readily dispersible form is an integral part, are exempt provided that:	Instruments, clocks, electronic tubes or apparatus, or similar manufactured goods, of which the radioactive material in a non-readily disparable form is a component part are similarly exempted provided:

	PRESENT ICC	PROPOSED ICC	IAEA
INSTRUMENTS, etc. (cont'd)		(1) Products are securely packed in strong outside containers; (2) The content of any single item, device or container of luminous compounds does not exceed the exempt quantities specified for small quantities except that for tritium-activated luminous devices and compounds, the content limit for each device or container of compounds shall be 10 curies; (3) The content of any single package containing such devices shall be the limit permitted for Type A packaging; and (4) The total dose rate of the radiation at any readily accessible external surface of the package at any time during transportation does not exceed 0.4 milliroentgen per hour or equivalent, except when shipped as carload or truckload shipments or transported by private carrier, the total dose rate of radiation at any readily accessible external surface of each package at any time during transportation does not exceed 2.0	(a) securely packed in strong shipping containers; and (b) external radiation does not exceed 10 mr/24 hrs. (13.3.)

	PRESENT ICC	PROPOSED ICC	IAEA
		milliroentgens per hour or equivalent. (73.392(b))	
SWITCHBOARDS, etc.	Switchboard or similar apparatus containing electronic tubes of which radioactive materials is a component part are exempt when shipped in carload or truckload lots or when transported by private motor carrier provided the gamma radiation at any readily accessible surface of the units when prepared for shipment does not exceed 50 mr/24 hrs. (73.392(b)(1))	No equivalent.	No equivalent.
LOW SPECIFIC ACTIVITY MATERIALS	Radioactive materials such as ores, residues, salts of natural uranium and thorium, etc. of low activity packed in strong tight containers are exempt from requirements for shipments in carload lots by rail freight only provide the dose rates or equivalents do not exceed 10 mr/hr at 12 feet from any surface of the car and 10 mr/hr at 5 feet from either end surface of the car. There must be no loose radioactive material in the car and the shipment must be braced so as to prevent leakage or shift of lading under conditions normally incident to	The materials mentioned below are exempt when shipped in carload lots or strong tight packages and when the subsequent conditions are met. (1) Unirradiated uranium, natural and depleted, and unirradiated natural thorium in a non-friable solid form other than powder or granules or contained in an inert metal cover or other substantial coating such that the surface of the uranium or thorium is not exposed, provided that beryllium, graphite, or heavy water in more than trace amounts 4/ are not included in any package containing natural uranium.	The materials mentioned below are exempt when shipped in carload lots or strong tight packages and when the subsequent conditions are met. Unirradiated uranium, containing 0.72% U 235 by weight, or less, and unirradiated thorium, in a non-friable, massive solid form or contained in an inert metal cover or other substantial coating such that the surface of the uranium or thorium is not exposed*, provided that: (a) the radioactive materials are packed in a manner which will prevent the ingress of moisture and movement of the material within the package or vehicle; and (b) beryllium, graphite (pile-grade)

	PRESENT ICC	PROPOSED ICC	IAEA
LOW SPECIFIC ACTIVITY MATERIALS (cont'd)	transport. The car must be placarded by the shipper. (73.392(c))	(2) Ores and concentrates of ores of natural uranium and natural thorium and intermediate products i.e. in-process materials in gaseous, liquid, sludge or solid form arising from the processing of natural thorium before enrichment or irradiation of the uranium or thorium but not including refined isotopes, such as radium, thorium 228, or actinium. (3) Low activity materials (i.e., residues from the processing of natural uranium and natural thorium; wastes such as building rubble, metal, wood and fabric scrap, glassware, paper and cardboard; reactor and process plant wastes in liquid or solid form; sludges and ashes from incinerators containing radioactive materials) in which the estimated maximum radioactivity content for radioactive materials in Group I does not exceed 0.1 microcurie per gram in radioactive material in sludge or solid form, or 0.1 microcurie per milliliter in radioactive material in liquid form. If radioactive materials in Group I are not present, the limits shall be 1.0 microcurie per gram and 1.0 microcurie per milliliter, respectively.	or heavy water are not included in the package containing the radioactive materials. * For instance, aluminium-clad fuel elements. (14.1.1) Ores and concentrates (of ores) of natural uranium and natural thorium; (14.1.2) Intermediate products, i.e. in-process materials in gaseous, liquid, sludge or solid form arising from the processing of natural uranium and thorium before enrichment or irradiation of the uranium or thorium, but not including refined isotopes of radium. (14.1.3) Low-activity materials, i.e. residues from the processing of natural uranium and thorium; wastes such as building rubble, metal, wood and fabric scrap, glassware, paper and cardboard; reactor and process plant wastes in liquid or solid form; sludges and ashes from incinerators containing radioactive materials; or other materials, provided that, in such low-activity materials, the estimated maximum radioactivity content for radioactive materials in Group I does not exceed:

	PRESENT ICC	PROPOSED ICC	IAEA
LOW SPECIFIC ACTIVITY MATERIALS (cont'd)		Conditions (1) Shipments must be in such form and quantity that the estimated total radioactive content of any one container, or when in bulk, of any one car or motor vehicle, does not exceed 100 millicuries of any material in Group I, or 1 curie of any material in Group II, or 20 curies of any material in Group III. If the shipment contains radioactive materials of more than one toxicity group the number of curies of Group I multiplied by 10 plus the number of curies of Group II plus one-twentieth of the number of curies of Group III shall not exceed one. (2) Packed in strong, leaktight packages or loaded in cars or motor vehicles specially designed to ensure that there shall be no leakage under conditions normally incident to transportation. (3) There shall be no loose radioactive materials in any car or motor vehicle, except as provided by subparagraph (1). Specially designed cars or motor vehicles shall not be used for transportation of any other material until decontaminated to the levels specified in §73.398(a).	0.1 uc/g in the case of radioactive material in sludge or solid form; or 0.1 uc/ml in the case of radioactive material in liquid form; where radioactive materials in Group I are not present, the limits shall be, respectively, 1.0 uc/g and 1.0 uc/ml. (14.1.4) Conditions In the case of intermediate products and low-activity materials, or of ores and concentrates (of ores) of natural uranium and natural thorium, shipments shall be made in such form and quantity that the estimated total radioactive content of any one container, vehicle or compartment does not exceed: 100 mc of any material in Group I; 1 c of any material in Group II; 20 c of any material in Group III;or for any combination of radioactive materials involving more than one toxicity group: (total activity in mc of Group I) X 10 + (total activity in c of Group II) + (total activity in c of Group III) X 1/20 shall be equal to or less than 1 c. (14.1.5)

	PRESENT ICC	PROPOSED ICC	IAEA
LOW SPECIFIC ACTIVITY MATERIALS (cont'd)		(4) Except when handling is supervised by the Atomic Energy Commission, shipments must be loaded by the consignor or his duly authorized agent and unloaded by the consignee or his duly authorized agent. (5) The external radiation shall not exceed 200 milliroentgens per hour or equivalent at any readily accessible surface of the car or motor vehicle or 10 milliroentgens per hour or equivalent at a distance of 12 feet from any surface of the car or motor vehicle or 10 milliroentgens per hour or equivalent at a distance of 5 feet from either end surface of car or motor vehicle. In addition, for shipments by motor vehicle the radiation level shall not exceed 2 milliroentgens per hour or equivalent at any place within the driver's compartment. (6) The car or motor vehicle shall be placarded in accordance with Section 74.541 or 77.823 of this chapter. (73.392(d)) 4/ For the purposes of this section, quantities of heavy water (i.e., deuterium or D), beryllium (Be) or graphite (i.e., carbon or C) if any is present shall be considered to be trace amounts if the following atomic ratios are not exceeded: D: U = 5 Be: U = 1 C: U=15 (73.392(c))	The radioactive materials shall be packed in strong, leak-proof packages or loaded in vehicles or compartments specially designed to ensure that there will be no leakage under conditions normally incident to transport. (14.2) There shall be no loose radioactive materials in any conveyance. In the case of specially designed conveyances or compartments referred to in sub-section 14.2, these conveyances or compartments shall not be used for transport of other goods until decontaminated to the levels specified in Table X, Annex I. (14.3) The consignor or consignee shall ensure that the conditions of packaging, loading and unloading for which they are responsible are such that operating personnel are not likely to be exposed to doses of radiation in excess of the permissible levels referred to in sub-section 4.2. (14.4) The shipment shall be loaded so as to prevent loss or dispersion or shift of lading under conditions normally incident to transport. (14.5)

	PRESENT ICC	PROPOSED ICC	IAEA
LOW SPECIFIC ACTIVITY MATERIALS (cont'd)			Shipments shall be loaded and unloaded by or under the direct supervision of the consignor or of the consignee. (14.6) In the case of transport by rail the X- or gamma-radiation or equivalent shall not exceed 200 mr/h at any readily accessible exterior surface of the vehicle nor 10 mr/h at a distance of 3 m (10 ft) from any surface of the vehicle and 10 mr/h at a distance of 1.6 m (5 ft) from either end-surface of the car. (14.7.2.3) In the case of transport by rail or road, the vehicle shall be labelled or marked in accordance with sub-section 8.2 (14.7.2.4)
URANIUM AND THORIUM IN SPECIAL FORM	No equivalent.	Radioactive materials as specified in this paragraph, are exempt from specification packaging. (1) Unirradiated uranium, natural and depleted, and unirradiated natural thorium, in a non-friable solid form or contained in an inert metal cover or other substantial coating such that the surface of the uranium or thorium is not exposed provided that:	As stated above in the Low Specific Activity Materials section, the IAEA exempts uranium and thorium provided certain conditions of handling, packaging, loss-prevention, labeling, and supervision are met.

	PRESENT ICC	PROPOSED ICC	IAEA
URANIUM AND THORIUM IN SPECIAL FORM (cont'd)		(i) The radioactive materials are packed in a manner which will prevent the movement of the metal within the package or vehicle; and (ii) Beryllium, graphite, or heavy water, except in trace amounts [1/], are not included in the package containing natural uranium. Note 1: For the purposes of this section, quantities of heavy water (i.e., deuterium or D), beryllium (Be), or graphite (i.e., carbon or C) if any is present shall be considered to be trace amounts if the following atomic ratios are not exceeded: D: U = 5 Be: U = 1 C: U = 15 (2) Magnesium-thorium alloys containing not more than 4% nominal thorium 232, in a non-friable solid form, which are in bundles, boxes, barrels or crates. (3) Each package must be labeled with the label described in §73.414 (a)(4). (73.392(e))	

	PRESENT ICC	PROPOSED ICC	IAEA
ORES	No equivalent.	Domestic ores while in transit between a mine and the first point of processing are exempt. (73.392(f))	No equivalent.
EMPTY PACKAGES	Empty packages must meet the requirements for SMALL QUANTITIES and must be labeled "EMPTY" except for truckload or carload shipments. (73.29(e) and (f))	Empty packages which contained radioactive materials are exempt provided: (1) The inside contamination levels do not exceed: (a) For Group I, either 10 uc or .01 uc/100 cm^2; (b) For Group II, 0.1 mc; or (c) For Group III, 1.0 mc. (2) The package is in good condition and securely closed. (3) The external surface dose rate does not exceed an equivalent of 0.4 mr/hr. (4) Non-fixed external surface contamination shall not exceed .01 uc/100 cm^2 for beta and gamma emitters and .0001 uc/100 cm^2 for alpha emitters. The packages must be labeled "EMPTY" except for truckload or carload shipments. When compliance with requirement (1) above cannot be achieved or determined, the package will be labeled with both an empty label and the appropriate yellow or white label. Contents shall be identified as "FIXED INTERNAL CONTAMINATION ONLY." (73.29(e), (f) and (g))	Similarly exempted are empty packages provided: (i) The receptacle which contained the radioactive material has been decontaminated and the remaining contents are estimated not to exceed: (a) For Group I: 1 uc if assessed in quantity, or 10^{-4} uc/cm^2 if assessed as a contamination level; (b) For Group II: 0.1 mc; or (c) For Group III: 1 mc. consignor must certify this provision has been met; (ii) transport documents show package has contained radioactive materials; and (iii) package is in good condition, securely closed and with external radiation and non-fixed contamination level as for packages of exempted small quantities. (13.4)

	PRESENT ICC	PROPOSED ICC	IAEA
PACKAGING			
PACKAGING STANDARDS	All non-exempt radioactive materials must be packed in specified containers or containers approved by the Bureau of Explosives. Radioactive materials that present special hazards because of long biological half-lives (i.e. radium, plutonium, etc.) must, in addition, be packed in inside metal containers specification 2R, or other inside containers approved by the Bureau of Explosives. (73.393(a) and (f))	Standards for shipping containers are divided into two types as follows: (1) Type A packaging shall be adequate to prevent loss or dispersal of the radioactive contents and to retain the shielding efficiency under normal conditions of transport. (2) Type B packaging shall be adequate to prevent loss or dispersal of radioactive materials and to retain the shielding efficiency under normal conditions and under severe accident conditions. In the regulations, various types of specified containers are grouped into the Type A or Type B category. (73.391(d) 73.394, and 73.395)	Same as the proposed ICC. The IAEA has not, however, approved of specific designs. (5.1.3)
COMPETENT AUTHORITY APPROVAL	All containers must meet the published specifications or it must have the approval of the Bureau of Explosives. (73.393(a) and (f))	Type A or Type B packages which do not meet any of the published specifications must be approved by the Bureau of Explosives. (73.395)	Type B packaging design shall be approved by the competent authority of the country in which the shipment originates. The application for approval shall indicate the nature of the accident postulated and the design specifications made to withstand the effects of such an accident. (5.1.4)

	PRESENT ICC	PROPOSED ICC	IAEA
MINIMUM DIMENSIONS	The smallest dimension of any outside shipping container for radioactive materials must be not less than 4 inches. (73.393(d))	The smallest dimension of any outside shipping container for radioactive materials must be not less than 4 inches. (73.394(a))	Smallest external dimension of the total packaging assembly shall be not less than 10 cm (4 in.) (5.2.) Class II packages - not less than 15 cm (6 in.) (15.2.2.2.)
ACTIVITY LIMITS	For shipment by rail freight, rail express or highway, the activity limits are: (a) 2000 millicuries of radium or other members of the radium family of elements. (b) 2700 millicuries of any other radioactive substance, except for (c) 300 curies of solid cesium 137, cobalt 60, gold 198, or iridium 192. (73.391(b) and (c))	Type A packaging Group I - 100 microcuries Group II - 10 millicuries Group III - 2 curies Group IV Solids and encapsulated sources - 20 curies Tritium (H 3) and Krypton 85 - 50 curies Type B packaging Group I - 20 curies Group II - 20 curies Group III - 200 curies Group IV Solids and encapsulated sources - 5000 curies Tritium (H 3) and Krypton 85 - 3000 curies Proportionate mixtures are also permitted. (73.393)	Type A packaging Group I - 100 microcurie Group II - 10 millicurie Group III - 2 curies massive non-friable solids - 20 curies Type B packaging Group I - 20 curies Group II - 20 curies Group III - 200 curies massive non-friable solids - 2000 curies (6.2.1.5. and 6.2.1.1.) Proportionate mixtures are also permitted.

	PRESENT ICC	PROPOSED ICC	IAEA
LABELS AND RADIATION LEVELS	Red labels are required for packages with Group I or Group II materials. The surface dose rate must not exceed 200 mr/hr or equivalent. The dose rate at one meter from the source must be below 10 mr/hr or the beta equivalent and below the equivalent of 2 mr/hr for neutrons. Blue labels are required for packages with Group III materials. The surface dose rate must be below 10 mr/24 hrs. (73.393(e), (g), (h), (j), 73.394, and 73.414(a) and (b))	Low specific activity labels for uranium or thorium are white. White labels are required for packages with a surface dose rate which does not exceed 0.4 mr/hr or equivalent. Yellow labels required for packages with surface dose rate in excess of 0.4 mr/hr. Dose rate may not exceed 200 mr/hr at surface or 10 mr/hr one meter from surface of package. Red labels are prescribed for packages which require special approval of the Bureau of Explosives. Quantities in excess of Type A and Type B limits, fissile materials in excess of the exempt quantities, and radiation levels in excess of 200 mr/hr and 10 mr/hr are conditions which required special approval and red labels. (73.292(e)(3), 73.414(a) and 73.397)	The IAEA has no low specific activity labels. White labels are required for packages with surface dose rates which do not exceed 10 mr/24 hr or equivalent. Yellow labels are prescribed for packages with surface and one-meter dose rates which do not exceed the equivalent of 200 mr/hr and 10 mr/hr, respectively. The IAEA prescribes yellow and white labels for large sources. (7.1, 7.2, 8.1.1, 8.1.2, and 16.2.3)
VEHICLE PLACARDS	Red placards must be used for all rail shipments of radioactive materials. (74.541(b) and 74.553)	A yellow "Radioactive" placard is required for cars containing packages bearing radioactive white labels and/or yellow labels and carloads of radioactive ores, residues, or similar materials requiring placards. A red "Radioactive" placard is required for cars containing packages bearing radioactive red labels. (74.541(b))	All vehicles containing non-exempt radioactive materials shall be clearly labelled or otherwise clearly marked with black on a white background. (8.2)

	PRESENT ICC	PROPOSED ICC	IAEA
PACKING AND STORAGE			
PACKAGE AND UNIT LIMITS	Not more than 40 units of radioactive material (red or yellow label) shall be transported in any car or vehicle or stored in any location at one time. (75.655(j)(4))	As present ICC 75.655(j)(4)).	Not more than 50 packages of WHITE or YELLOW category to be in any one vehicle, aircraft or ship's hold at one time. (10.2.1.) Number of packages with YELLOW labels in any one vehicle or aircraft shall be so limited that total number of radiation units does not exceed 40. (10.2.2.) Radiation units in a storeroom not to exceed 40, unless special provisions made for radiation safety. (10.2.3.)
PACKAGE-FILM SEPARATION DISTANCES	As IAEA.	As IAEA.	
PACKAGE-PASSENGER SEPARATION DISTANCES	Total Number of Radiation Units: 1 to 10 — Distances in Feet to Areas that may be Continuously Occupied by Passengers or Employees, or from dividing Partition of a Combination Car.: 3	Total Number of Units: 1 to 10 — Distance in Feet to Area that may be Continuously Occupied by Passengers or Employees, or from dividing Partition of a Combination Car.: 5	Total Number of Radiation Units Shown on the Packages / Separation Distances in Feet for Carriage or Storage Lasting from 8 to 24 hours. 0 to 10 — 5 11 to 20 — 7 21 to 30 — 9 31 to 40 — 10 (Table VII)

	PRESENT ICC	PROPOSED ICC	IAEA
PACKAGE-PASSENGER SEPARATION DISTANCES (cont'd)	11 to 20 4 21 to 30 5 31 to 40 6 (75.655(j)(2))	11 to 20 7 21 to 30 9 31 to 40 10 (75.655(j)(2))	
CONTAMINATION LEVELS	Box cars and motor vehicles shall not have contamination which exceeds: 10 mr/24 hrs for beta and gamma contamination, or 500 dpm/100 cm^2 for the average alpha contamination. (73.395(a))	Cars, motor vehicles, adjacent cargo, area, etc. shall not be contaminated to levels which exceed: 0.4 mr/hr for beta-gamma contamination, or 0.001 uc/100 cm^2 for the average alpha contamination. Car and motor vehicles used solely for the transportation of radioactive materials are exempt from the above requirements provided the interior contamination levels do not exceed: 2 mr/hr at one-meter for beta-gamma contamination, or 0.01 uc/100 cm^2 for the average alpha contamination. Contamination on packages must not exceed: .01 uc/100 cm^2 for beta and gamma emitters. .001 uc/100 cm^2 for alpha emitters. (73.398(a) and (b), and 73.393(c))	When handed over for transport non-fixed radioactive contamination on any external surface shall not exceed: 10^{-4} uc/cm^2 for beta or gamma emitters 10^{-5} uc/cm^2 for alpha emitters (11.1. Table X, Annex I)

	PRESENT ICC	PROPOSED ICC	IAEA
FISSILE MATERIALS	The U. S. A.E.C. exercises regulatory control over the possession, use, storage and transfer of fissile materials.	Except for the exempt quantities of 10 uc of Pu239, 100 uc of Pu 241, 1 mc of U 233, or 16 gm of U 235, all shipments shall be made in accordance with the procedures approved by the Bureau of Explosives. In addition, when shipments exceed 9 grams of Pu239 or Pu 241 or 16 grams of U 233 or U 235, the shipments shall be made in accordance with procedures approved by the U. S. A.E.C. and the shipper must certify that the package meets AEC requirements. The original copy of the certification must accompany the shipment. (73.392(a)(2), 73.396(a) and (b))	Shipments in the following categories do not need to comply with the additional requirements (including competent authority approval) for fissile materials (detailed in Section 15): (i) Shipments containing in any one package quantities up to: Pu 9 g U 233 16 g U 235 16 g and proportionate mixtures (ii) Shipments in which the only fissile material present is uranium in which the U 235 content is no higher than 0.72% by weight, provided that packages containing such materials do not contain more than trace quantities of beryllium, graphite (pile-grade) or heavy water. (iii) Shipments of aqueous or other solutions in which the only fissile material present is: (a) Uranium, in any enrichment, in which the H:U235 atomic ratio is greater than 5 200, corresponding to a U 235 concentration in common aqueous solutions of less than 5 g/l; or

	PRESENT ICC	PROPOSED ICC	IAEA
FISSILE MATERIALS (cont'd)			(b) Plutonium in which the H: Pu 239 atomic ratio is greater than 7 600, corresponding to a Pu 239 concentration in common aqueous solutions of less than 3.5 g/l, provided that the material being transported is such that homogeneity will be assured at all times, and that no portion in the solution will be, at any time during transport, in excess of that concentration. (6.2.2.) Other shipments require competent authority approval. Labels (white and yellow) are required if the radiation levels are sufficiently high. (6.2.2. and 15.)

DISCUSSION AND COMMENTS

The Interagency Committee expects to transmit the proposed ICC Revision to the ICC for its consideration sometime this month. From there it will be up to the Interstate Commerce Commission in terms of dealing with this in accordance with their regular rule making procedures. The ICC's usual rule making procedures do include provisions for public comments.

We have dealt with the return of empty containers. As a matter of fact, there is a proposed label which will say "Empty Containers". This would be the only label used if the contamination inside were below a certain limit. If the contamination is above that limit, the container must be placarded either with the white or the yellow label, in addition to the "Empty" label. Some of these containers which are returned still contain a substantial amount of residual activity and may have a radiation level which may be above 10 mr in 24 hours. These would require an "Empty" label plus a label which characterizes the nature of the package.

The rate question has to be dealt with separately.

Mr. George of the Bureau of Explosives stated that there was a need for changes in the regulations and criticality is one of the things that should be covered better. Although he felt that the changes should not be as extensive as have been proposed. That does not mean that industry is not better pleased or will not be better pleased with the new proposal than they are with what we have.

There has been one opportunity already to comment on the "Tech Standards". The next opportunity to comment formally on the proposed revisions will be after these have been referred to the Interstate Commerce Commission. The Interstate Commerce Commission will then, itself, have to make a decision as to whether or not it feels these proposals are appropriate. If so, the ICC would be expected to adopt appropriate procedures to get pertinent comment on them in accordance with their usual practice for doing so.

The technique with which the proposed limits are to be measured are not specified. The present ICC regulations named one instrument to be used for determining the levels. With respect to contamination we specify so much per unit area without specifying exactly how these measurements are to be made, and, although the wipe test is suggested, the instrument or technique for assessing is not specified.

Session Chairman: I could not help but notice some rather shaking heads when Mr. Rogers was describing the various labels that were put up here. I think we ought to try to remember that this world that we are living in and the world of radiation and atomic energy is very much more complicated than it was 15 years ago. To some extent these additional complications, the different quantities of material, types of material that are either being shipped or will soon be shipped, are bound to be reflected in proposed new regulations. I would ask you to remember one other factor and that is that such things as these labels are meant to serve the interest of a great variety of different groups. I think so often each of us tend to see whether or not a particular labelling proposal or set of labelling proposals will serve our own particular purposes and perhaps more that we don't know about so we feel they are too complicated. But if you have sat here in AEC at Germantown with the ICC and listened to complaints of labor unions, public health groups, from railroads, truck carriers, bridge, turnpike and port authorities, behind each of these complications, which hopefully may turn out to be not as complicated a study as they were initially, you will see the purpose for them.

The comment was made that for a long time the ICC regulations seemed rather than being too liberal to have been a little bit too restrictive. Instead of having the quantity cut down as this proposal apparently does in essentially almost every category with the exception of the contained source of radium and krypton, probably the ICC containers would be better for an increased amount of material rather than a decreased amount of material. Also the ICC Spec. 55, which is essentially close to type B could go up higher. The only two places they have gone up is solids and encapsulated sources and tritium (H3) and krypton 85.

The quantity which you can ship without special approval has gone up in each category. That is you do not need special approval from category 3 below, which is 20 curies of group 1 or 2; 200 curies of group 3.

With respect to the container, there are many containers which are presently handling 2.7 curies that can in all likelihood meet the type B specification, including Spec. 55 or maybe some modification of Spec. 55. In that case, you could go up to 20 curies of group 1 and 2, which are the most hazardous materials and up to 200 curies of group 3. That is a very substantial increase over the present requirement. However, for type A containers, which includes most of the present ICC Spec. containers, reductions in quantity are made. Also, the exempt quantities on the high toxicity grouping have been reduced from 125 microcuries to 10 microcuries. The other toxicity groups are about the same or have been raised.

Session Chairman:

Our next speaker is Mr. Barker, Chief of the Engineering Standards Branch, Division of Licensing and Regulation, U. S. Atomic Energy Commission.

U. S. ATOMIC ENERGY COMMISSION REGULATIONS PERTAINING TO FISSILE MATERIALS

by

Robert F. Barker, Chief
Engineering Standards Branch
Division of Licensing and Regulation

Introduction

10 CFR 71

In September 1957, the Atomic Energy Commission issued a proposed regulation for public comment which was designed to assure that appropriate precautions were taken in connection with the shipment of special nuclear or fissile material. After making some revisions to take account of the comments received, 10 CFR Part 71, "Regulations to Protect Against Accidental Conditions of Criticality in the Shipment of Special Nuclear Material" was issued as an effective regulation in October 1958.

In general, 10 CFR 71 provides that the procedures to be used in shipping quantities of fissile material in excess of certain specified quantities must be approved by the AEC. Those specified quantities depend on the method of shipment. Up to 350 grams of U-235, 200 grams of U-233 or 200 grams of plutonium may be carried by the licensee before AEC approval is needed. However, above 100 grams of U-235, 60 grams of U-233 or 60 grams of plutonium to be given to a carrier for transportation require AEC approval.

This means that approval must be obtained for most shipments of fissile material. Much of the criteria used in granting approvals is found in the "Nuclear Safety Guide", TID 7016, Rev. 1 and "Guide to Shipment of U-235 Enriched Uranium Materials", TID 7019.

A revision of 10 CFR 71 is under consideration by the AEC to incorporate specifications for shipping containers and the criteria for approval of the procedures for packaging and shipping of fissile material developed over the past several years. This will be taken largely from TID 7016, Rev. 1 with some modifications to conform with more recent data or to provide a greater degree of safety. These criteria include basic limits for individual containers in terms of mass, container volume, inside diameter of a cylinder and slab thickness. Also limits are established for arrays of containers. Under specified conditions allowances may be made in terms of increasing the basic limits for varying U-235 enrichments, cylinder shapes, reduced density for undiluted metal or when diluted with other elements.

Certain small quantities when packaged in individual packages may be safely transported without further control. These quantities, 9 grams of plutonium or 16 grams of U-233 or U-235 would be exempted from AEC approval altogether.

Based on the precautions that must be taken during transport, all other fissile material shipments would require AEC approval and would be classed in the appropriate one of three classes.

In applying for approval of a method of shipment of fissile material, the criteria contained in the revision of 10 CFR 71 under consideration, may be used or any other criteria for nuclear safety (i.e., control of accidental criticality) based on the specific procedures and material involved.

The nuclear safety of the proposed method of shipment must be supported by experimental data, calculations or plans for special controls.

Some aspects related to the choice of conditions to be assumed in applying the criteria are discussed later in the paper.

10 CFR 72

In March 1960, the AEC first issued a proposed rule for public comment to establish general criteria for the design of shipping containers, and to establish shipping requirements to protect against accidental criticality and radiation exposure in the shipment of irradiated fuel elements. In light of the many comments and suggestions received, a second proposed rule was issued in September 1961, again for public comment because of the major changes made in the criteria.

The later criteria applies to the shipment of solid irradiated fuel elements containing 2000 curies or more. The design of the shipping cask must be capable of withstanding certain minimum specifications as to ruggedness. These include exposure to an internal pressure of no less than 20 psig, a 15 foot free fall on any side, a one hour standard fire, and a 6 inch diameter puncture test. Other structural design requirements mainly related to lifting devices and other appurtenances are also given. Pressurized shipments up to 50 pounds per square inch are permitted.

Other parts of the criteria deal with shielding, criticality limits and heat transfer requirements.

In issuing 10 CFR 72 proposed, it was recognized that certain of the criteria involved complex technical information that was not complete. Where possible, tables or acceptable values were given to augment the criteria. Concurrently, tests were initiated to develop the needed data to provide more satisfactory information.

At this time, although a great many useful comments have been received and some revisions in the proposed rule might be accomplished, the results of the more informative tests are only now being received. These results will be taken into account in a revision of the proposed rule to be issued as an effective regulation.

Nuclear Safety

Careless handling of fissile materials can cause a critical assembly to be formed which can dissipate a large amount of energy. If released in a short time, this energy can cause considerable damage and is always accompanied by

a serious radiation hazard. The burst of radiation could possibly be lethal within a radius of several feet and produce radiation injury to personnel over much larger distances. The prompt evacuation of the personnel could prevent serious radiation exposures from fission products. However, decontamination after a criticality incident could prove formidable and an explosion-type of energy release could cause considerable mechanical damage.

The likelihood of a chain reaction or critical configuration is effected by several factors: the weight percent or enrichment of U-235 if it is uranium, concentration of the fissile isotope present, density, quantity, geometry, amount of neutron reflection provided by surrounding material, degree of moderation which is normally due to hydrogen, presence of neutron absorbers or poisons and interaction between neighboring amounts of fissile material.

In transport, prevention of the occurrence of criticality is of great importance. Each package in which special nuclear material is shipped must provide a degree of safety adequate to insure that under normal shipping conditions and in case of credible accident conditions, the individual package will not produce conditions of accidental criticality. In most cases assuming the most effective degree of moderation and full reflection, an adequate degree of safety can be achieved with a simple package design. However, under certain circumstances, if one assumes less than the most effective degree of moderation or geometry control, breech of the container could in itself result in conditions approaching those necessary for accidental criticality. Under these latter circumstances either additional safety factors must be included in making the shipment or the packaging design must be such that it insures that credible accidents will not cause disruption of that component of the packaging which ensures nuclear safety. Usually the inner container is that important component.

In each case positive action must be taken to prevent the occurrence of any single event which is likely to cause criticality. Furthermore, the shipment must be made under conditions such that at least two unlikely and unrelated events must take place concurrently before the conditions of criticality can be achieved. Such events or changes should be unlikely because of positive action taken to reduce the actual chance of occurrence to an insignificant level.

As we know, the transport environment is not subject to control as in the case of the laboratory or the plant. In establishing limits on the contents of the individual package, certain influences from the environment are usually assumed. For example, the package may be subjected to heavy rain, snow or sleet even under normal transport conditions. Therefore, the degree of reflection which is most reactive is assumed. Also, unless some special provisions are made to prevent inleakage of water, such as very sturdy double container, water is assumed to leak into the inner container to the extent that the contents are thoroughly wetted. When the package is so designed that the contents do not fill the inner volume, then it may be necessary to assume the most effective degree of moderation possible with light water.

With the assumptions established, several sources may be used to determine the permissible contents of a package. As mentioned above, the criteria being considered for 10 CFR 71 includes limits on mass, container volume, cylinder diameter and slab thickness.

Interaction Between Two or More Individual Units

Once the individual package contents are established and are shown to be adequately packaged, the number of such packages which can be brought

together safely must be determined and means provided for maintaining that control.

In determining the allowable number of packages, the conditions under which interaction is evaluated must assume the most reactive conditions which could occur at any time during the process of transport including the loading, processing, intermediate storage or holding on a dock as well as possible accidental conditions.

Loss of neutrons by small volumes or by an increased surface to volume ratio, spacing to reduce interaction, and moderator-poison combinations for control are among the simple systems that can be employed to provide nuclear safety in shipment. Based on the conditions assumed, the allowable number of each design of container for the amount of material in the individual unit is determined.

Classes of Shipments

Fissile material shipments have been divided into three classes depending on the control involved during shipment. These classes were first proposed in regulations developed by the International Atomic Energy Agency.1/ Class I Safe from Neutron Interaction; Class II Nuclearly Safe in any Arrangement in Limited Numbers; and Class III Nuclearly Safe under Special Arrangement.

Exemptions

Certain small quantities mentioned earlier are exempt from AEC approval. Present ICC regulations require packages for radioactive material have no external dimension less than 4 inches. Calculations made by the United Kingdom and referred to by the IAEA show that for packages having at least one liter volume and assuming a credible number of such packages to be 250, up to 9 grams of Pu-239 or Pu-241 or 16 grams of U-233 or U-235 in each package will be safe. Therefore, those quantities in a single package are being considered as exempt from criticality control. To provide some control on the number of exempt packages, likely to collect together, no more than 5 exempt packages are to be given to a single carrier by any one shipper in a day.

Class I

One way of permitting large numbers of packages to be shipped together safely is for the package to include a moderator-poison system that will slow down and capture neutrons emitted by fission of the fissile material. Packaging which consists of a cadmium lined central cavity surrounded by 4 inches of wood has been shown to act as a neutron absorber. That is when such packaging is exposed to a flux of fission neutrons, the number of neutrons emitted from the package are less than the number entering. This then permits large numbers of such packages, in any arrangement, to be collected and shipped together.

1/ "Regulations for the Safe Transport of Radioactive Material", IAEA Safety Series No. 6, May 1961.

Class II

Over the past 13 years, the ICC regulations have limited the number of radioactive material packages on each vehicle and in any one storage area to no more than "40 radiation units". A radiation unit referred to 1 milliroentgen per hour at one meter from the contents of the package. The "40 unit" limit is being extended to fissile material packages by arbitrarily assigning a number to each fissile material package determined by dividing 40 by the allowable number of such packages.

However, because there remains some uncertainty as to the observance of the "40 unit" rule, it has been agreed that the allowable number of fissile material packages to which the "40 unit" rule should be applied must be so limited that at least 5 times that number could come together under normal conditions of transport and still be sub-critical.

The "40 unit" rule is applied to Class II Fissile Material shipments. Class II shipments are nuclearly safe in any arrangement because of limits on the contents and limits on the number of packages shipped together. This means that as long as the "40 unit" limitation is observed, Class II packages can be safely stacked in any arrangement and mixed with other radioactive material shipments, except for Class III fissile material shipments. Class III shipments are limited so that observing the restriction on Class III will prevent mixing or commingling of that class with Class II shipments. The "40 unit" limit for Class II packages provides some additional safety factor in that mixing of regular radioactive material packages with fissile material packages reduces the contribution to the radiation level and also reduces the possibility of criticality.

The "safety factor" of 5 for commingling has been applied to a situation which already has safety factors in addition to that for commingling due to the inherent safety of the individual packages. It is obvious that the assumptions of the most reactive, credible conditions in determining the individual unit and assessing the interaction between such units on the basis of the most reactive, credible conditions in most cases will add many degrees of safety to the factor of 5.

One set of limits on contents and allowable numbers for Class II was developed by the IAEA and presented in Annex III of the IAEA regulations.[2/] The AEC is considering that application and as a second criteria, restricting the contents of the total "40 unit" shipment to 1/5th the minimum critical mass. Spacing is not of importance in the second case and can be neglected but the contents (i.e., 1/5th the minimum critical mass) are very small.

Class III

The likelihood of neutrons from one package affecting the fissile material in any other package depends on the size represented by the fissile material in the other packages. One method of assessing the interaction between packages is by determining the amount of the total solid angle represented by the sum of the packages seen by the central package. The spacing between the inner containers of packages is important in reducing the size represented by the neighboring fissile material.

2/ IAEA Safety Series No. 6

Each method of making a Class III special arrangement shipment must be individually reviewed and the adequacy of the provision assessed both for normal and accident conditions. In so doing, "special handling" other than "exclusive use" and "courier" may be used provided it offers the necessary degree of safety. For Class III shipments, the means of control must be provided throughout the course of transport as described in the approval.

Other means of providing nuclear safety include administratively or physically restricting the geometry or spacing of amounts of fissile material during shipment without building that control into the packaging. Theoretically a very long pipe of the "safe" inside diameter, or a "safe" slab thickness quite extensive in two dimensions, would provide an adequate degree of nuclear safety. The diameter or thickness limits and most of the other controls of an administrative nature require that no fissile material be commingled or intermixed or added to the shipment as planned. These and some other limits require some control during transport beyond that normally provided by the carrier. Means of assuring that the specified orientation or spacing is maintained usually will require that the shipper provide for "exclusive use" of the carrying vehicle. If he uses his own vehicle, the shipper can provide the controls himself or if he has a "truckload" or "carload" lot by which he loads and seals the car, that will suffice. Control also may be provided by a courier who is knowledgeable and has authority to properly supervise the shipment and assure its safety through the course of its travels.

Heat

The release and absorption of radiation results in the production of other forms of energy, primarily heat. When the source is an alpha emitting material, as in the case of plutonium, essentially all of the energy is absorbed in the material itself - that is by self absorption. On the other hand, roughly half of the energy of gamma radiation is uaually dissipated in the shield. Where hundreds of curies of alpha or gamma emitters are involved, the amount of heat produced, depending on the shape of the source, may require special design to transfer the heat from the source. For example, calculations show that a sphere of plutonium metal 2 inches in diameter may require heat transfer because of the low surface area to volume ratio and the quantity of heat which may be produced in the sphere. Similarly a long rod of plutonium metal which is more than 1 inch in diameter must be provided with heat control.

With very large curie quantities of gamma emitters, not only will the amount of heat produced in the source be a problem but also, the hundred of thousands of curies in irradiated fuel elements produce enough heat in the source and shield that additional provisions must be added to the container to dissipate the heat. Fins to transfer heat to the surrounding air may be attached to the outside of the package or even elaborate heat exchanging systems may be provided.

Radiation Safety

Fissile material emits radiation and has radiotoxicity as other radioactive materials. In general, the shipment of all fissile materials is subject to the regulations of other agencies having jursidiction over transportation, i.e., the Interstate Commerce Commission, the Coast Guard, the Federal Aviation Agency and the Post Office Department as well as state and local regulatory groups.

For irradiated fuel elements the AEC regulation (10 CFR 72 proposed) has gone into these radiation levels and contamination control in some detail. However, tie down or storage and the regular aspects of transportation, are not covered in the AEC regulations. With respect to other special nuclear materials, nuclear safety and heat transfer are the prime considerations in AEC approval.

Tests of Packaging

In our discussions of criticality, we have referred to normal conditions of transport and then proceeded to take the liberty of assigning certain conditions which one must assume occur under "normal conditions". The same is true of accident conditions. The usual method of devising conditions for insuring safety during transport are to provide against the most severe conditions which are likely to be encountered in transport. Establishing the severity of those conditions is a matter of administrative judgment based in part on the studies which have been conducted of past accident records. This involves both an assessment of the degree of severity and the likelihood of that degree being achieved under any likely accident conditions.

The AEC has established extreme conditions for assessing or testing of containers designed to carry fissile material which it considers adequate to provide for severe accident conditions. This assumes that there is a reasonable assurance that a shipping container designed and constructed in accordance with the specifications in 10 CFR Part 71 or Part 72, which are based on those extreme conditions, will withstand accident conditions to which such a container is likely to be exposed. Among the extreme conditions assumed are impact, puncture, fire and immersion in water.

The likelihood of any particular type of container being subjected to any one of the extreme conditions postulated is influenced by the weight of that container. For example, in 10 CFR 72 which deals with very heavy casks used for the shipment of irradiated fuel elements, a 15 foot free fall on a large flat unyielding surface is one of the performance requirements to be met. On the other hand, in the design of a package for shipment of other special nuclear or fissile material, the packaging must be capable of withstanding a 30 foot free fall on a large flat unyielding surface. The difference is based on the anticipated difference in weight of containers and the likelihood of each being subjected to equivalent forces.

As another example, the consequences of total loss of shielding in the case of irradiated fuel elements is much more severe than that associated with other fissile material. In part because this fact is related to loss of shielding which might occur in a fire, the requirements for the design of a package for shipment of irradiated fuel elements is such that it must be capable of withstanding exposure to the standard one hour fire. Packaging for other fissile material must be subjected only to a 10 minute fire test.

Of major consequence in assessing the adequacy of the design of packaging is the formulation of the point of failure for each of the tests. In general, packaging must be adequate to: (1) control contamination and internal exposure by prevention of release of the material, i.e., containment; (2) limit the radiation emitted from the package to acceptable limits, i.e., shielding; (3) insure against accidental criticality (for fissile material); and (4) dissipate safely the heat produced by the radiation released by the radioactive material.

Failure to fulfill those primary functions under either normal conditions or accident conditions indicates an inadequacy on the part of the package design.

However, test criteria which is assumed to provide an overall adequate package design, must be further identified with specific failure points for each test item. For example, in the case of irradiated fuel shipping casks, the cask must withstand a 15 foot free fall without (1) exceeding the ultimate strength of any structural portion of the cask or (2) deforming to an extent which would permit the escape of fuel elements or portions of them or permit the level of external radiation to exceed one roentgen per hour at one meter from the surface of the cask. In the design of some shipping casks, an energy absorbing structure is placed around the cask which is intended to deform and thereby absorb the impact energy.

In the case of unirradiated fissile material packages, the packaging may include an outer container which provides spacing between the fissile material contents and any neighboring package, e.g. a "birdcage". In this case the spacing is of such importance that one must restrict the loss of spacing when such package is subjected to the impact test. Therefore, for unirradiated fissile material shipping containers, the package must be capable of withstanding a 30 foot free fall with (1) no loss of contents from the inner container and (2) no more than a 10% reduction in any spacing measured from the outside of the inner container to the outside of the outer container.

It is highly desirable that each type of package be tested to determine its capability of withstanding specified test conditions. However, it is not intended that a container which has been subjected to the conditions assumed to represent a credible accident be capable of further use. Also the cost of large shipping containers is such that testing of each prototype is not practical. Hence, it is appropriate in applying for approval of any container to provide (1) the results of engineering assessment of the packaging design provided all assumptions made in the assessment are stated, (2) the results of the tests of models of the packaging design or of mock-ups representing certain details or methods of construction used in the packaging design, (3) extrapolation from results of tests of similar packaging design with similar construction features, (4) details of shipping experience with packages of similar design, (5) other information, arguments or evidence applicable to the design, or (6) actual tests of prototypes of design.

Approval by the AEC of a particular design or type of packaging will usually provide that any number of such containers may be used by that licensee for the purpose authorized in his license provided adequate quality control is exercised to insure that each container meets the specifications contained in the approval and that the construction affords the degree of safety specified in the design. Any significant changes in design or any use other than that specified in the approval in the license must be reconsidered by the AEC and specific approval granted.

Summary

We have seen that accidents cannot be regulated but conditions can be postulated which represent the degree of severity which packaging is expected to withstand irrespective of the actual accident conditions. These postulated conditions include impact, puncture, fire, immersion in water. The point of failure of a type of packaging depends on the conditions to be protected against.

The design of the packaging for controlling criticality during transport depends on several variables related to the contents, including the enrichment of the material (if U-235 is present), the moderator ratio, the type and form of the material. A variety of limits or combinations of limits

may be required to insure nuclear safety of the individual units and of the collection of more than one unit in one place. Whatever individual unit is chosen, that is mass, volume or dimension, and whatever means of controlling interaction between units or between arrays of units is chosen, such as spacing, isolation, etc., the overall system of nuclear safety shall insure that the limits and means of controlling interaction are observed at all times.

Heat and radiation safety also must be considered in the design of packaging for shipment of fissile material.

DISCUSSION AND COMMENTS

In regard to the 10 minute fire test for some unirradiated fissile material containers, many shipments of special nuclear material have been made. So far as we are aware the involvement in a fire has not contributed to a criticality problem. This would not affect the AEC's requirements in 10 CFR 72. This is being considered in a proposed revision of 10 CFR Part 71, also an AEC regulation, which would incorporate criticality criteria. This revision deals primarily with criticality and insofar as radiotoxicity is concerned a fire in transport is probably not going to contribute to criticality. It may be of very much concern insofar as radiotoxicity is concerned and because of that the ICC revision may impose on the plutonium shipment very much more stringent requirements at very much smaller quantities than will the AEC's criticality control.

For example, our concern with criticality starts only at nine grams of plutonium, nine grams being the quantity the British have calculated to be a quantity that could be exempt from criticality control provided one insures that there are no more than 250 packages getting together in one spot.

Nine grams, however, would be close to a half a curie of plutonium 239.

Shipment of irradiated fuel elements, so far as we have considered to date, will still be required to be shipped in containers which are capable of withstanding a one-hour fire. For "cold" or unirradiated fissile material the concern is not about shielding as in the case of irradiated fuel. The concern is only about separation of material. We may hear from a special test which has been carried on just recently in the UK where they have actually exposed an aluminum capsule containing some material to a fire test and the material was still confined within the aluminum. But at least our present considerations are that there would be no more than a ten-minute fire test for certain of the shipping containers for fissile material that is not irradiated.

If there is a problem from the higher specific activity material or from the radiotoxicity standpoint, then there may still be very stringent fire test requirements. The ICC revision for quantities in excess of 10 millicuries of plutonium will likely require a container to be capable of withstanding a one-hour fire test. This is not considered necessary for low toxicity material such as slightly enriched uranium.

Consideration has been given to varying the height of the drop test based on the weight of the container. The British have looked at various weights of containers insofar as impact tests are involved. This leads one to re-evaluate perhaps the need for an impact test or at least the height of the impact test. However, at present our consideration has not led us to change the height of drop for an excessive weight.

You will notice in the British document one very grave concern is about packages which are put in the parcel post because those small packages are subjected to rather severe impacts. So, it turns out that one might have a curve that started with a sizeable drop test for very small packages. Very large packages, such as an irradiated fuel container, should continue down to some lower drop height.

It was noted that the radiotoxicity grouping is based on the reports of the International Commission for Radiological Protection considering exposure principally by inhalation. Ingestion also was considered. The detailed basis is given in Safety Series No. 7 of the International Atomic Energy Agency Publication.

SECOND DAY - SESSION II CONT'D
TUESDAY - DECEMBER 4, 1962

Lester R. Rogers, AEC, Session Chairman presiding.

Session Chairman: Gentlemen, we welcome you again this morning to the Symposium.

In no other area is compatability of regulations more important than the field of transportation of radioactive materials. Certainly as the Atomic Energy industry grows, domestically to worldwide, the movement of materials in international transportation is extremely important.

We are pleased to have representatives from several foreign countries with us in this symposium.

Our first speaker this morning is Mr. W. A. Martin, senior inspector of the Dangerous Commodity Section of the Board of Transport Commissioners of Canada.

DEVELOPMENT OF TRANSPORTATION REGULATIONS IN CANADA

by

W. A. MARTIN, SENIOR INSPECTOR
BOARD OF TRANSPORT COMMISSIONERS
CANADA

As your representative from the Board of Transport Commissioners of Canada and on behalf of the other Canadian delegates who won't have an opportunity to address you, I wish to thank the Atomic Energy Commission for their invitation to attend this Symposium.

The Symposium on radioactive material containers is of particular interest to the Canadian Transport Authority at this time because of the possibility of adopting uniform transportation regulations is currently under study in Canada.

Before dealing further with possible future regulations, it may be appropriate to comment briefly on the regulations now in effect.

The Board of Transport Commissioners' role in the state of transportation of dangerous commodities in Canada is similar to that in the U. S. except that the Board's jurisdiction in this field is limited to transportation by rail.

Because the Board's requirements for the packaging of radioactive materials are the most comprehensive regulations now in effect in Canada, I propose to enter into them in more detail later on. Although the road transportation of radioactive materials is subject to provincial regulation, none of the provinces prescribes packaging requirements for radioactive material. The Province of Ontario, which is further advanced in this regard than any of the other provinces, does prescribe insurance and marketing requirements for vehicles and in the past two years has been preparing regulations for dangerous commodities similar to those issued by the Board of Transport Commissioners.

The air transportation of radioactive materials in Canada is controlled by the Civil Air Operations and Regulations Division of the Department of Transport. Prescribed regulations are those of the International Air Transport Association by air.

The radioactive materials moving by ship in Canadian waters are subject to regulations of the Steamship Inspection Branch of the Department of Transport. These regulations are published under the title, "Dangerous Goods, Shipping Regulations".

Under the Atomic Energy Control Act certain powers pertaining to the packaging and use of radioactive materials have been granted to the Atomic Energy Control Board. You can see that we have quite a multitude of regulatory bodies that are concerned with the transportation of radioactive materials. Packaging,

labeling and handling requirements for shipments of radioactive materials offered for transportation by rail in Canada are prescribed in Board Circular No. 286, and in the Board's publications, regulations for transportation of dangerous commodities by rail.

The latter regulations are quite similar to those issued by the Interstate Commerce Commission. In fact, in so far as they concern radioactive materials, the Board's regulations are identical to those issued by the Interstate Commerce Commission and prescribe requirements for rail shipments of radioactive materials not exceeding total radioactivity of 300 curies.

Radioactive materials in quantities exceeding the total radioactive limits prescribed in the Board's regulations are known as large source shipments. The suitability of a large source container is determined by heating, radiation and design specialists in accordance with provisions of Board Circular No. 286. Our source containers approved by the Board bear the mark "B.T.C., S.P.", followed by the number, BTC standing for the Board of Transport Commissioners, and SP standing for special permit. Board Circular No. 286, to which I previously referred, was issued in July 1960, to serve as a guide in the approval of large source containers.

Prior to the issuance of this circular, a good deal of time was wasted in establishing for its submission the basis for an acceptable design and in the absence of advance agreement on general standards of design and performance, there was the tendency to accept compromises which in some cases did not prove to be in the best interests of all concerned.

Although Board Circular No. 286 issued approximately two years before Pamphlet No. 6, and 7 were available, the basic packaging recommendations of the International Atomic Energy Agency.

The maximum credible accident concept is employed in the circular as a general standard for container design, but in no case shall container design for lesser impact than that produced by a drop of 20 feet on a solid floor. The distance was based on a suggestion that the drop of less than 20 feet would occur if a cable or brake of a train should actually fail while a package was being hoisted in a gondola car.

Once the applicant can prove that the container or the target surface is capable of sustaining a deformation of greater than half an inch without a loss of source material or shielding effectiveness, it is assumed that a 20 foot drop will produce a deceleration of 500 G. Experience gained during the past two years in examination of 20 large source container designs indicates that 500 G is a practical impact standard for containers with weight in the half ton to 15 ton range, and with more or less sperical, short cylindrical or other compact case.

Our experience in designing containers with two flat surfaces indicates that design of such containers poses special problems not encountered in the design of previously measured containers and drop test data would be most useful in such cases.

When Board Circular 286 was first issued, very little information concerning fire resistance standards was available to us. As a result of this deficiency, the only fire resistance requirement of the circular is that the shell shall be fabricated from steel or other material equivalent in strength and fire resistance. However, a good deal more information is available now, and the more complete standard can possibly be prepared.

The current volume of applications for BTC approval of large source containers is insufficient to justify employment by the Board of a team of radiation and design specialists. For this reason it is the Board's practice to refer to various technical groups of the National Research Council. The Board relies on the accuracy of the structural strength, and the criticality team of the Atomic Energy of Canada, Limited, for advice on nuclear safety of fissionable material.

Applications for Board approval must be accompanied by drawings and supporting information as described in some detail in the Board's Circular 286.

In November 1961, at the request of the Minister of Transport, technical representatives of various federal agencies concerned with the safe transportation of radioactive materials in Canada formed a committee for the purpose of studying the possibility of developing uniform regulations for radioactive material. This committee, which has met approximately twice a month since February 1962 has recently concluded that the general criteria of IAEA's Pamphlet Nos. 6 and 7 are satisfactory bases for drafting of uniform regulations. However, the committee is not in complete accord with some of the individual recommendations made by the IAEA. In fact the committee considers and has so recommended that revision of the following section of Pamphlet No. 6 would be desirable.

Item 1. Section 5.1.4 which prescribes individual approval of all Type B packaging is considered to be an impractical requirement. It has been suggested that Type B packaging requirements for quantities of materials not exceeding the amounts prescribed in Sections 6.2.1.1 and 6.2.1.5 should be covered by a specification similar to BTC or ICC Specification 55.

6.2.1.1 describes up to 2000 curies in Type B packaging in non-friable massive solid form.

6.2.1.5 permits up to 20 curies of Group I and II materials in Type B, and up to 200 curies of Group III.

Item 2. The committee considers it advisable to prescribe Type A packaging by specification with provision for the acceptance of non-specification Type B packages where deviation from the specification requirements appear to be justified.

Item 3. Section 6.2.2.3, 15.2.1 and 15.2.2 and other sections dealing with fissile materials as well as Annex II and Annex III are considered to be too permissive. It has been suggested that all shipments of fissile materials in excess of the exempted quantities prescribed in Section 6.2.2.1 should be approved as nuclearly safe by a panel of nuclear specialists. The proposed procedure would require permits to be renewed annually.

Item 4. It is the committee's opinion that Section 7.3 pertaining to measuring instruments should prescribe that all such instruments be checked annually for accuracy by an approved testing laboratory.

Item 5. Section 13.3 which prescribes exemptions for apparatus and similar manufactured goods is considered to be too permissive. It is believed that the exemption should be limited to certain named commodities, such as luminous dials and electronic tubes.

Item 6. The radiation limit of 10 MR/HR at 3 meters as prescribed in Section 16.2.3.2(a)(ii) for large source containers moving as carload or truckload lots is considered to be undesirable as a design criterion for large source containers, although some relaxation from the normal yellow category

requirement of 10 MR/HR at one meter might be considered by the authority having jurisdiction, if such a relaxation appeared to be justified by the circumstances applying to a particular shipment.

The large volume of radioactive materials moving between Canada and the U. S. makes it highly desirable that transportation regulations of the two countries be as uniform as possible. For this reason, it is suggested that the Interagency Committees of Canada and the United States establish a line of communication for the exchange of information on the development of their respective proposals and particularly for those proposals pertaining to large source shipments, and to standards which differ appreciably from those recommended by the International Atomic Energy Agency.

In closing, I would like to make some general remarks with regard to some of the previous papers. With reference to Mr. Patterson's paper pertaining to the accident experience with radioactive material shipments in the U. S. during the five year period from 1957 to 1961, I would like to read a statement attributed to a physicist, Mr. Harry Lustig:

> "Over the long run", he said, "it does not matter how small the probability of an accident is per unit time. It is mathematically demonstrable that as time goes on this probability approaches certainty."

If this statement is correct, one must conclude that although they have yet to experience a maximum credible accident in the United States or Canada, sooner or later such an event will occur. To this conclusion I add my own observation that the magnitude of an accident is often determined by chance circumstances over which little or no control can be exercised and presently available accident statistics for radioactive material shipments may cover a period of sufficient length to permit an accurate evaluation of the effect of chance circumstances on accidents involving large source shipments. I would, therefore, suggest that although our accident record is a favorable one, we cannot afford to relax on our standards. "Eternal vigilance is the price of safety."

Session Chairman:

Within the United Kingdom a great deal of work has been done particularly in the past two or three years on the development of transport regulations. They have very heavily supported the efforts of the International Atomic Energy Agency, providing much of the material for the basis of the IAEA regulations.

Likewise, within the United Kingdom itself they have been busy in developing transportation regulations based on the IAEA concepts. We will now hear from Mr. Roy Gibson of the Authority Health and Safety Branch of the United Kingdom.

DEVELOPMENT OF TRANSPORT REGULATIONS IN THE UNITED KINGDOM

by
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Introduction

1. Dangerous goods have been transported in the United Kingdom by road, rail, sea and air for many years, and the transport of many classes is controlled by statute. In some cases statutory control is exercised by means of direct regulation: for example, Home Office regulations govern the carriage by road of petroleum and explosives. In other cases detailed guidance in the form of an Official Code of Practice, backed by regulations in general terms, has been adopted as the more appropriate and satisfactory method of control. The carriage of dangerous goods by sea has long been controlled in this fashion. Again, some carriers, notably the railways, have devised their own conditions of carriage, normally in consultation with the transport authorities concerned, to control the movement of specified classes of dangerous goods. Thus it will be seen that there is no set pattern in the U.K. and it is against this background that the term "transport regulations" is used in this paper. Generally, where transport of radioactive materials has been brought under control, this has been done by extending the existing form and method of control on other so-called "dangerous goods".

Early U.K. regulations

Sea

2. Carriage of dangerous goods by sea in U.K. registered ships, or in other ships which load or discharge in U.K. waters, is governed by the Merchant Shipping (Dangerous Goods) Rules, 1952 made under Section 23 of the Merchant Shipping (Safety Convention) Act, 1949. The rules require inter alia that dangerous goods shall be properly described, clearly marked, adequately packed and appropriately stowed. Guidance on how to fulfill these general requirements is given in the report of the Standing Advisory Committee on the Carriage of Dangerous Goods and Explosives in Ships, better known as the "Blue Book" (ref. 1), which is revised from time to time. In 1957 Section 10

of the Blue Book was expanded to include radioactive substances. This entry very broadly followed the pattern of the U.S. Interstate Commerce Commission (I.C.C.), but without detail and included segregation tables based on work carried out by the U.K.A.E.A. at Harwell (ref. 2). Although it has no direct statutory force, the formula "packed in accordance with the Blue Book" has enabled a large number of shipments to be carried by sea with very little bother.

Rail

3. The obligations of the railways as common carriers have never extended to the carriage of dangerous goods: in other words, they are entitled to decline to accept dangerous goods. The British Transport Commission therefore devise their own terms and conditions for the carriage of dangerous goods. The Transport Act 1962, which re-organises the nationalised railways, preserves this position for the new Railways Board which will be set up as one of the successor Boards to the Commission. Responsibility for the carriage by rail of dangerous goods in general has thus been left with the British Transport Commission and they have issued, through the medium of the Railway Clearing House, a "list of dangerous goods and conditions of acceptance". For some years the British Railways have been accepting consignments of radioactive materials provided that they complied with their stated conditions. (Consignments falling outside the normal conditions have been accepted after negotiation between the U.K.A.E.A. and the British Railways specialists.)

U.K. Policy

4. In the U.K. the Radioactive Substances Advisory Committee, appointed under the Radioactive Substances Act of 1948, provides Government with high-level scientific advice on all aspects of radiological protection. Accordingly, at a special meeting on 30th June, 1961, the committee was asked to consider the implications of the transport regulations produced by the International Atomic Energy Agency (I.A.E.A.) (ref. 3). The committee recommended that they should be used as the basis for all U.K. regulations on this subject, and the appropriate government departments were asked to proceed accordingly.

I.A.E.A. regulations

5. It would be appropriate here to interrupt the narrative of the development of the U.K. transport regulations to look at the appearance of the I.A.E.A. regulations on the scene.

6. On 31st March, 1959, the United Nations Committee of Experts, charged with studying the international carriage of dangerous goods, recommended to its parent Committee that the I.A.E.A. be entrusted with the drafting of recommendations on the transport of radioactive substances within the general principles of the Committee of Experts on the Transport of Dangerous Goods and in consultation with the

United Nations and the Specialized Agencies concerned. This was endorsed on 17th July, 1959, by a Resolution of the Economic and Social Council of the United Nations.

7. This marks the date of the raising of the official United Nations umbrella under which I.A.E.A. activities in this field could be conducted, but the origin of the I.A.E.A. work came some months earlier. It was in the last quarter of 1958 that the Swedish Governor to the Agency proposed that a Working Party should be appointed to produce an I.A.E.A. manual on the transport of radioactive materials.

8. Two Panels were appointed - one to deal with radioisotopes and materials of low specific activity, and the other to consider large radioactive sources of fissile materials - and the first meetings were held in Vienna in April, 1959. The recommendations made by the two Panels were woven into a single set of regulations and these were approved by the Agency Board of Governors at their meeting on 13th September, 1960. The Board authorised the Director General to apply the regulations to Agency operations; to recommend them to Member States and other international organisations as a basis for their own regulations; and to propose to the United Nations that the regulations be included in the recommendations of the United Nations Committee of Experts for further work on the transport of dangerous goods.

9. In the Plenary Session on 30th September, 1960, the General Conference went on to pass a resolution submitted jointly by Poland and the U.K. welcoming the regulations as a step towards the desired end of facilitating the international transport of radioactive materials by the adoption of harmonised safety regulations. With this endorsement the regulations were sent for printing and appeared in the middle of 1961.

10. In the U.K.A.E.A. we have committed a sizeable effort in support of the Agency's efforts to produce realistic transport regulations. It is true to say, however, that U.K. support for the I.A.E.A. regulations derives not from pride of partial authorship, but rather from an early recognition that compatibility between national and international regulations is an absolute necessity for the atomic energy industry.

Present state of U.K. regulations

11. For some years there has been in existence a Ministry of Transport Working Party on Dangerous Goods. The terms of reference of this Working Party have recently been amended to make it a forum for the discussion of problems relating to the carriage of dangerous goods by more than one mode of transport. It has now become the practice for draft regulations to be considered by this Committee and it is also used as a briefing committee for U.K. representatives to international meetings where international transport regulations are drafted.

Sea

12. The first set of British I.A.E.A.-type regulations to receive approval was the revised draft of the relevant section of the Blue Book. This was produced by the Ministry of Transport in consultation with the U.K.A.E.A. and is based largely on the I.A.E.A. regulations. It contains nonetheless a number of modifications which are intended to represent a logical extension to the I.A.E.A. regulations. The most important of these modifications are listed in Appendix A to this paper.

13. The Radioactive Substances Advisory Committee (see para. 4 above) considered the revised draft of the Blue Book on 9th November, 1962, and agreed that it should go forward for publication. The Committee decided, however, to appoint a separate panel to consider all regulations governing the carriage of radioactive materials. This panel will not, of course, concern itself with matters of drafting - this will continue to be supervised by the Working Party on Dangerous Goods - but will concentrate on an examination of the radiological bases of the regulations.

14. The U.K.A.E.A. welcome the appointment of this panel as a means of ensuring thoughtful and compatible national regulations on this subject.

Rail

15. The Explosives Committee of the British Transport Commission is the technical committee charged with producing conditions of carriage for dangerous goods, and at a meeting at the beginning of October 1962, this committee approved the final draft of "regulations" for the carriage of radioactive materials by rail. The new draft closely follows the I.A.E.A. regulations and account has also been taken of the new R.I.D. (ref. 4) regulations which came into force in Europe from 1st June, 1962.

Road

16. Regulations to govern the carriage of radioactive materials by road are being prepared and they will be made under section 5(2) of the Radioactive Substances Act, 1948. [The writ of the Ministry of Transport in relation to road transport runs only in Great Britain, but it would be hoped that the Northern Ireland Government would make similar provisions.] Compressed gases and calcium carbide are already subject to the provisions of the Petroleum Act and explosives are of course already dealt with under the Explosives Act.

17. A number of special factors are involved in the control of road carriage. For one thing, there is no tradition of specific statutory control; although there is, of course, a general legal obligation for safe carriage so as not to endanger life and limb of persons on the carrying or other vehicles and the general public. Secondly, a consignor of radioactive material can use his own vehicle or that of

a haulage contractor; and the number of potential haulage contractors for this purpose is in the tens of thousands, some of whose vehicle fleets vary from one van or truck upwards. Thirdly, compared to the rail or sea carrier, the road carrier has less at stake - a vehicle and its driver. Fourthly, road transport covers many casual and miscellaneous movements, such as simple transfers from one hospital to another of a single radioactive source, and the transport of sources used by civil engineers, as well as the more regular and larger consignments, travelling direct or on a journey ancillary to rail, sea or air transport. At present, most consignments are probably carried by or under the direction of the U.K.A.E.A. or some responsible, expert undertaking, such as C.E.G.B.; but as the use of radioactive materials grows, consignors and carriers needing more guidance will come increasingly into the field.

18. At first sight, therefore, it would appear to be much more necessary to control road movements by precise detailed statutory regulations, that is to say, that the statutory regulations should embody detailed requirements following those of the I.A.E.A. regulations. There are, however, difficulties in the U.K. in drafting statutory regulations for such a technical and complex subject and in enforcing such regulations by the normal processes of law.

19. The alternative which has been adopted is a method roughly similar to that of the "Blue Book" method. It is important that the respective responsibilities of the consignor, the carrier, the vehicle driver and anyone else concerned shall be quite clear. Here matters are helped by the fact that the more technical, complex requirements almost all relate to the form and make-up of the consignment including such matters as activity, radiation and containment limits. The consignor almost ex hypothesi must be expert in such matters. Thus in relation to consignors, regulations in very general terms backed by a detailed Code of Practice, are thought by our Ministry of Transport to be appropriate. For others who may be affected (carriers, drivers, the public) the regulations would be more precise and detailed.

20. Legal requirements therefore, while restricted to the essential minimum, will set out in different degrees of detail the various legal duties which devolve on parties, but avoid so far as possible any technicalities. These will be supplemented by a comprehensive Code of Practice setting out precisely what are considered to be the conditions of safe carriage, including such matters as radiation and contamination limits, safe limits for fissile materials, and activity limits appropriate to various categories of consignment.

Ports

21. Port authorities already control the movement of explosives and petroleum spirit and allied substances by means of bye-laws made under the Explosives Act 1875 and the Petroleum Consolidation Act, 1928. In addition certain major port authorities such as the Port of London have special regulations and conditions relating to the handling of dangerous goods. There are no specific powers under the legislation

relating to radioactive substances to enable port authorities to make bye-laws controlling their handling in ports, but many authorities have general bye-law making powers under their harbour legislation which might cover the movement of these materials in harbours and ports.

22. It is clearly important that port authorities should be able to identify the category of a consignment from its appearance, markings and accompanying documents; that they should know whether any precautions should be taken at the quayside and in storage sheds and also what to do in the event of an accident. With these points in mind a draft Code of Practice for the conveyance of radioactive materials through ports is in course of preparation by the Ministry of Transport and will be discussed with port authorities (with whom there have been earlier soundings). There must clearly be consistency of treatment of these substances while in transit and the Code of Practice will seek to impose temporary storage and transit conditions which are in line with general transport requirements.

Air

23. The regulation of the transport of radioactive materials by air in the United Kingdom differs from that relating to movement by surface transport. International traffic is the dominant factor, and there is no detailed national code of practice in this country relating to air transport such as there is for railways and shipping.

24. Article 34 of the Air Navigation Order 1960 provides that dangerous goods may not be carried in any aircraft in or over the U.K. or in any aircraft registered in the U.K. wherever it may be, without the written permission of the Minister of Aviation. Most air transport operators serving the U.K. have been given general permission to carry goods in accordance with the regulations relating to the carriage of restricted articles by air prepared by the International Air Transport Association (I.A.T.A.) (ref. 5).

25. These regulations have been in force a number of years and have worked successfully in permitting, without any serious incidents, the transport by air of an ever-increasing volume of radioactive materials. Shipments by air in or from the U.K. now amount to about 20,000 consignments a year, and since their transport by air started 13 years ago they have totalled about 140,000 consignments.

Post

26. The General Post Office (G.P.O.) annual guide includes a brief reference to radioactive materials. Only packages approved by the G.P.O. can be used to transmit radioactive materials and a sample of the actual package is required rather than design drawings. Provided that the package and the chemical and physical form of radioactive contents have been approved, the only stipulation is that radiation at the external surface must not exceed 10 mr/24-hrs. The weight limitations effectively restrict the activity which can be put into a posted package.

Summary of the present position

27. Practical regulations on the I.A.E.A. model thus exist in the U.K. for the carriage of radioactive materials by sea and by rail; compatible regulations are being produced for road transport. By air we use the I.A.T.A. regulations, and through the mails we can send small amounts under carefully controlled conditions.

Packaging approval

28. We should like in this paper to examine in particular detail some of the problems connected with the formulation of acceptable standards of packaging, and to indicate how these are being tackled in the U.K. Safe transport of radioactive materials necessitates that the peculiar hazards (i.e. contamination, irradiation and possibly criticality and self-heating) shall be controlled throughout the transport operations. Broadly speaking this is done in two ways:

(a) by controls built into the packaging; and

(b) by operational procedures.

Most transport operations require a combination of both methods. It is generally simpler, but not always practicable, to rely mainly on the first method which is the one it would be appropriate to discuss in this paper.

Definition of terms

29. Before going any further, it would perhaps be helpful to define a few of the terms to be used:

(a) Receptacle - that which immediately contains the material to be transported.

(b) Container - that which holds, restrains or encloses any article or commodity or articles or commodities to be stored or transported.

(c) Packaging - the assembled packing apparatus (this may consist of one or more containers, and may include any incorporated safety devices, such as shielding).

(d) Package - the packaging together with its contents as presented for transport.

30. The indiscriminate use of these terms in the past, both in regulations and in U.K.A.E.A. domestic documents, has led to difficulties of interpretation and to some confusion. Transport regulations should be primarily concerned with complete packages, loads and consignments, and only to a minor extent with the constituent containers and packaging details. There is a need, we believe, for definitions of these terms to be embodied in regulations.

We realise that this represents a council of perfection because many of the regulations governing the carriage of non-radioactive "dangerous goods" already make use of one or more of these terms in an unco-ordinated way. Moreover, some have acquired a specialised meaning which it would be hard to shed. Changes of nomenclature are as difficult to affect as those of national boundaries, but we feel that regulations, and papers about regulations, should at least embody an explanation of the terms they employ.

Packaging Standards

31. In transport regulations, an attempt is made to reconcile the probability of accident with the injury capability of various consignments, by requiring the use of packaging of different standards. This principle was already well-developed for radioactive material transport, but the I.A.E.A. regulations embody an important improvement on older regulations for this traffic in that detailed packaging specifications, although similar to those in older regulations, are mainly given as examples and are not mandatory. The I.A.E.A. regulations confine themselves to specifying the objects to be attained by the packaging standards. They state what is to be achieved, but only suggest how it is to be achieved. Thus the designer is allowed the greatest possible freedom to develop new techniques for improving both safety and economy. This is a concept which we in the U.K.A.E.A. strongly support.

32. The packaging standards are in fact defined in terms of transport conditions of differing severity under which the four radioactivity hazards must be so controlled as to afford the same high degree of safety. The main sets of environmental conditions are:

(a) normal conditions of transport;

(b) normal conditions and minor transport accidents (or mishaps);

(c) normal conditions and the maximum credible accident relevant to the mode of transport.

Their relation to package contents and the associated hazards is as follows:

Normal conditions of transport

33. Normal conditions may be divided into:

(a) Climatic, depending mainly on the transport route, e.g. atmospheric temperature, humidity and pressure.

(b) Mechanical, depending mainly on the mode of transport, and arising both from the movement of the conveyance and from handling between conveyances.

Packaging able to control radioactivity hazards only under normal conditions may be used for materials of low radioactive concentrations (commonly called "low specific activity materials"); for very small quantities of radioactivity; or for small sources built into instruments and equipment (under certain conditions). Normal commercial packaging is capable of complying with this standard.

Minor accidents

34. A short drop when loading a package, e.g. when falling off the tailboard of a stationary truck, is regarded as a typical minor accident. Packaging able to control radioactivity hazards in minor accidents may be used for quantities of radioactivity insufficient to cause danger if accidentally released. Such packaging is designated "Type A" and corresponds roughly with I.A.T.A. Packaging Note 16(6).

Maximum credible accident

35. In I.A.E.A. parlance the maximum credible, or perhaps, as the French have called it, foreseeable, accident is the possible accident or series of accidents to be taken into account in relation to the mode of transport to be used. The requirement to be able to withstand the maximum credible accident is novel in the transport field, and its interpretation has been the subject of much argument. Packaging able to control radioactivity under these conditions must be used if the total radioactivity content exceeds that for which Type A packaging is allowed. Packaging of this standard is known as "Type B" and corresponds roughly with I.A.T.A. Packaging Note 44(6).

Competent authority approval

36. Transport regulations generally require Type B packaging to be approved by the competent transport authority of the country of origin. This is a minimum requirement. It is uncertain whether the consignee's country or the countries traversed en route will always be content to accept the consignor country's approval, or will impose their own approval as well. It would certainly simplify international transport operations, especially for packaging used for many different destinations abroad, if only one competent authority approval were required, but one cannot deny that standards vary widely between countries. Some countries may not be prepared to accept foreign approvals or may accept approvals only from certain specified countries.

Demonstration of ability to meet the packaging specification

Proving a packaging design

37. We now come to the main problem of packaging approval: how can a packaging design be shown to fulfil the seemingly simple requirements of ability to withstand normal conditions of transport, minor accidents of the maximum credible accident? First, there must be agreed precise descriptions of the transport environment and, second, procedures acceptable to the competent authorities must be devised, for proving

designs against the agreed conditions. An attempt to do this has been made in the U.K.A.E.A. by Fairbairn and Messenger in a report (ref. 6) now in advanced draft form and shortly to be published. Throughout its development, the U.K. competent transport authorities have been associated with this work and it is confidently expected that the recommendations in the published report will be broadly acceptable to them.

Methods of demonstration

38. The onus is on the consignor (or the sponsor of the design) to satisfy the approving authority that a packaging design is acceptable: he must make a case in defence of his design against the "environmental prosecution". The most obvious way of doing this is to subject sample packages to physical tests representing the environment. There are two difficulties:

The problem of realism in tests

The transport environment is too complex and variable to be exactly represented in controlled tests. The best that can be done is to adopt somewhat idealised artificial test conditions previously agreed by the competent authorities as providing satisfactory evidence that the packaging is able to withstand the real environment.

Availability of samples for testing

The second difficulty is one of economics. To justify confidence in the evidence of a test, the size of the sample must be adequate. The number of sets constructed to each design of radioactive material packaging is often small - frequently only one. If this is a large structure costing thousands of pounds the application of environmental tests that may be damaging (even though safety is demonstrated) is generally impracticable.

Alternative to testing

39. In the report (ref. 6) already referred to, it is recommended that specified test conditions be used in the first place merely to provide designers with numberical data as a basis for design and assessment. They should be at liberty to make their case by any of the following means:

(a) quantitative assessment;

(b) tests of models, packaging details or mock-ups representing the methods of construction to be used;

(c) extrapolation from test results for similar designs or designs embodying similar constructional features;

(d) reference to operational experience with packaging of similar design, including accidents and periodical inspections;

(e) any other evidence or reasoned argument.

40. Only when all these fail, need actual tests on sample packages be performed. Thus tests may well be demanded where new principles are employed, but designs on established lines will have an increasing background of experience against which they can be convincingly assessed.

Relaxations in testing

41. Even so it will seldom be necessary to perform all the relevant tests. Among possible grounds for exemption from tests or modification of test conditions are:

(a) Where accident tests are to be performed, related (but less severe) normal environmental tests should be waived.

(b) Tests may be omitted when packaging embodies features that render them inappropriate.

(c) Climatic tests may be modified or omitted if the design is to have a limited geographical area of use.

(d) When the proposed mode of transport and route for movement of a large source justifies postulation of a modified "maximum credible accident" or of less severe normal environmental conditions.

(e) The acquired body of experience may enable the competent transport authorities to approve packaging designs without subjecting samples to all scheduled tests.

Approval within U.K.A.E.A.

42. The design of all packaging for U.K.A.E.A. consignments of both Type A and Type B has to be approved by the Safeguards Division of the Authority Health and Safety Branch (A.H.S.B.) It is thus administratively convenient for the A.H.S.B. to make all submissions to competent authorities on behalf of all U.K.A.E.A. establishments. The main instrument of this approval procedure is the U.K.A.E.A. Packaging Design Approval Certificate which records, initially, A.H.S.B. approval and, subsequently, approvals by various competent authorities.

Designs complying with the regulations

43. Designs that fully comply with the packaging requirements of the regulations are sentenced in Category 1 and, if no competent authority approval is required by the regulations, may be taken into use at once. Designs which do not comply with the relevant regulations are

sentences in Category 2. For road transport, where statutory regulations have not yet been published, A.H.S.B. approval is not at present obligatory, but in fulfilment of the Authority's legal and moral obligations it is normally obtained. Pending the issue of road regulations approval is made on a temporary basis against the I.A.E.A. regulations on which the national regulations are to be modelled.

44. Where competent authority approval is required, A.H.S.B. approval can only be provisional, meaning that the packaging is acceptable to A.H.S.B. but cannot be used until A.H.S.B. has obtained the competent authority approval. When this has been received, the reference and date is recorded and A.H.S.B. approval becomes full.

45. Because of the present differences between regulations and between the requirements of various competent authorities, A.H.S.B. approval must be sub-divided into separate approvals against each set of regulations. Thus one may be able to give full A.H.S.B. approval as Type A packaging under one set of regulations, provisional A.H.S.B. approval pending approval against another set, and only Category 2 approval (necessitating the negotiation of approval of special arrangements with the competent authority) against a third set. This tedious complication underlines the very real need for consistency between transport regulations.

Designs not fully complying with the regulations

46. Some designs, although generally sound, do not fully comply with the packaging requirements (mostly designs prepared before the I.A.E.A. regulations were issued). These are sentences in Category 2 and the shortcomings briefly stated in notes which form the basis of "special arrangements", i.e. special operating procedures to compensate for the shortcomings, which A.H.S.B. negotiate with competent authorities. In such cases, competent authority approval of the packaging alone is not sought. (Where Type B packaging is sentenced in Category 2, it may still qualify as Type A packaging in Category 1. If it appears that such a double sentence will be useful it is recorded in the A.H.S.B. approval certificate).

Designs complying with the regulations but considered unsatisfactory

47. It is possible that, when regulations are applied to specific cases, they will be found to be insufficiently precise, ambiguous, unnecessarily restrictive or even hazardous. Approval must still be given against the literal meaning of statutory regulations, but where a design conforms with the statutory requirements and is nonetheless considered by A.H.S.B. to be inadequate, A.H.S.B. approval is only temporary and the certificate specifies the reason. If the regulations are over-restrictive, but recognise the "special arrangement" procedure, or are in reality conditions of carriage (e.g. British Railways Regulations), there is always the possibility of negotiating a safe practical solution with the competent authority. In either case representations to amend the regulations are made to the competent authority by A.H.S.B.

Obsolescent and obsolete designs

48. Designs that are unsatisfactory because they seriously depart from the current regulations or, although complying with the regulations, are not considered to give adequate safeguard (or are to be replaced or discarded for other reasons) are declared "obsolete" - usually by U.K.A.E.A. establishments on their own initiative. Sometimes immediate replacement is impossible and, provided that the current conditions of use are satisfactory, temporary approval, expiring at a certain date or on replacement, is given. Such designs are declared "obsolescent", which means that no more containers and other components may be manufactured to them.

Large sources

49. Where the intended activity content exceeds the normal limit for Type B packaging, the design must be approved for more specific contents as a "large source". So far only the R.I.D. (ref. 4) have implemented the I.A.E.A. regulations in this respect, although other regulations are expected to follow. Except under R.I.D., only provisional A.H.S.B. approval can be given and then a "special arrangement" transport operation must be negotiated. The "large source" approval procedure is similar to the "special arrangement" procedure.

50. This large source approval is much, but by no means entirely, concerned with heat dissipation. It is therefore intended that future A.H.S.B. large source approvals shall be in terms of a maximum heat output and a maximum ambient temperature. A.H.S.B. separately deal with approval of operating procedures for the transport of large sources, after the packaging approval has disclosed what special safeguards will be required.

Future developments

51. We have attempted in this paper to describe how the U.K. thinking on transport regulations has developed and in particular the importance we attach to the I.A.E.A. regulations. Before such an audience we do not need to argue the advantages of compatibility, but perhaps we can use the opportunity to emphasise the importance of obtaining the maximum uniformity in international transport regulations.

52. When the I.A.E.A. regulations were approved the Board of Governors asked the Director-General to arrange for them to be reviewed at appropriate intervals. To this end the Agency has appointed a Panel to meet in Vienna in March, 1963, to undertake a revision of the regulations. We understand that in addition to participants from 12 Member States with relevant experience, there will be representatives of 20 international organisations. Recognising the procedural complexities that are inevitable with such a large Panel, we remain hopeful that this wide representation will result in revised regulations which will be universally acceptable.

In particular we look for a reconciliation between the regulations of the I.A.E.A. and I.A.T.A. as a major step towards international compatibility.

References

1. The Report of the Ministry of Transport Standing Advisory Committee on the Carriage of Dangerous Goods and Explosives in Ships. HMSO 1957 (and amendment lists Nos. 1, 2, 3, and 4).

2. Isolation Distances required for Radioactive Materials in Ships by H. J. Gale and J. M. Chisholm, A.E.R.E. Report HP/M.113, 1956.

3. Regulations for the Safe Transport of Radioactive Materials. I.A.E.A. Safety Series No. 6. Vienna 1961.

4. International Convention concerning the substances and articles not to be accepted for carriage or to be accepted subject to certain conditions (R.I.D.) - HMSO 1959 (revised version effective from 1 June, 1962, now being printed).

5. I.A.T.A. regulations relating to the carriage of restricted articles by air: (current version: 7th Edition effective from 1 April, 1962) issued by the Traffic Director, I.A.T.A., Montreal, Canada.

6. Messenger, W. de L. M., and Fairbairn, A., "The Transport of Radioactive Materials. Interim Recommendations for the Application of Environmental Tests to the Approval of Packaging" to be published as AHSB(S)R.19.

Differences between the revised version of the U.K. "Blue Book" and the I.A.E.A. Regulations for the safe transport of radioactive materials.

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1. "Blue Book" dispenses with the 3/2 factor for calculating low energy gamma- and/or X-radiation dose rates. (1.1.5*)

2. "Blue Book" allows encapsulated materials (for which a specification is included) to be treated as massive non-friable solids. (6.2.1.1)

3. "Blue Book" exempts up to 1 microcurie of Group I radioisotopes, whereas I.A.E.A. permits no exemption for such materials. (13.2)

4. "Blue Book" adds a package limit for instruments of 100 times the exemption limits - i.e.

   100 microcuries of Group I
   10 millicuries of Group II
   100 millicuries of Group III (13.3)

5. "Blue Book" stipulates that after sustaining the maximum credible accident the emergent radiation at 1 metre from a Type B packaging should not exceed 1r/hr. I.A.E.A. contains no similar relaxation. (5.1.3)

6. "Blue Book" gives the minimum dimension for all packages as 4-inches, whereas I.A.E.A. stipulates a 6-inch minimum for Class II fissile consignments. (5.2 and 15.2.2.2)

7. "Blue Book" requires the trefoil symbol to be affixed to all containers of low specific activity materials. There is no similar I.A.E.A. requirement.

8. "Blue Book" specifies permissible quantities of beryllium, heavy water and graphite allowed

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*Bracketed references are to I.A.E.A. Safety Series No. 6

with natural uranium. Following atomic ratios must not be exceeded:

Be:U = 1; C:U = 15: and D:U = 5

I.A.E.A. refers either to "trace quantities" (6.2.2) or prohibits the materials altogether (14.1.1(b)).

9. In exempted aqueous solutions containing fissile fissile materials the "Blue Book" imposes mass limits when homogenity cannot be assumed:

U.233 and Pu	-	500 g
U.235	-	800 g

10. To simplify the calculation of segregation distances from stacks of low specific activity materials, the "Blue Book" permits - as an alternative to measuring the dose rate - the assumption of the following radiation unit equivalents:

chemical concentrates	-	2
thorium ores and physical concentrates	-	10
uranium ores and physical concentrates	-	40

Remarks by Mr. Gibson: I would like to thank the AEC for the invitation to attend the Symposium. We are very grateful for this opportunity. We are looking forward not only to meeting you or hearing your papers and having our own papers listened to, but also to meet you in the passages and to talk informally outside and to exchange views.

This slide is to explain the sort of organization we have in the United Kingdom for developing transport regulations. Those of you with engineering training will recognize that it looks like a flow sheet, but I must warn you not to look for an end-product, as you do in a flow sheet, because although we have several inputs on here, the amount of output is strictly limited.

We have in the center what we call competent authorities. We have Ministry of Transport, which deals with sea, with roads, with port and with rail as well. We have the British Railways who actually run the railways and at the moment they have not yet decided between them and the Minister of Transport, who is the competent authority for rail.

We have the Ministry of Aviation which looks after all internal and international flights by air. They of course are assisted by our National Airlines, BOAC and BEA.

We have on the official side what we call the Radioactive Substances Advisory Committee.

The object of this committee is to give government the best available technical advice on all things relating to atomic energy and all regulations before they are promulgated by any of our ministries or by any of our competent authorities must be looked at by this committee. It consists of the most eminent scientists that we have in the country. They have now found the transport regulations require close study, so they have appointed a transport panel. This will consist of about six people who will look at the technical basis of regulations and try to get uniformity and compatability on a national footing. So any regulations produced by our Ministry of Transport and the other people will be played into this committee here for them to look at.

Let me go back to the other side of the slide and show how these competent authorities get their regulations anyway. Most of them have not got technical representation in their ministries. They know all about the transport side but have little specialized knowledge on radioactive materials. They actually formed a dangerous goods working party which also includes people like the Atomic Energy Authority. We also have a service known as the Radiological Protection Service to give specialist advice and this is represented on the dangerous goods working party. It consists, when there is a full flood, of about 30 people. We have representatives of shipping interests, what you would call trucking companies, and the Atomic Energy Authority.

Out of this committee you get out drafts which come back into the Radioactive Substances Advisory Committee. You might think when you have gone that far, you are nearly home, and dry, but then you have to go to another group which is the Interdepartmental Committee on Atomic Safety and Health.

This committee has to decide whether it is right and proper for regulations which are technically acceptable because they have gone through this, the Radioactive Substances Advisory Committee and are administratively necessary.

If we look at the second slide, I thought it might be interesting to see how inside the Atomic Energy Authority in the UK we develop regulations. Our Authority Health and Safety Branch is the link with all of the government

departments. We have five operating groups, the production group, the research group, weapons, reactor and engineering, and quite apart and quite independent from these groups is our Authority Health and Safety Branch from which Toby Messenger and I come.

The renegade, Frank Dixon, comes from the research group. That is why he was disturbed when he was posted to the Health and Safety Branch in the programme yesterday.

Once again we have government by committee. We have first of all the Transport Container Advisory Panel and representatives on that panel from our operating groups. The Chairman is supplied by the AHSB, that is Alan Fairbairn, whose name may be familiar to some of you.

We have a Transport Criticality Working Party. Again we have a criticality specialist from each of those groups. We provide the Chairman, also a criticality specialist, from the Branch.

The third committee is our Transport Container Standardization Committee. The aim of this committee is to take approved designs and try to rationalize them, to produce preferred types: types that ought to be proceeded with in the future and generally to distill information and advice to design engineers.

Here the slide is getting a little blurred, but these are our group transport liaison officers. We have in each of these groups a single person who is our point of contact on formulation of regulations. It is his job to tell our branch where the regulatory shoe is pinching on the group foot, so to speak.

We let them tell us where the regulations as drafted are practical. We leave them to explain what kind of relaxation they are looking for, what kind of liberalizations. We in turn pass back to them the sort of work we would expect them to do in order to convince competent authorities that some relaxation is necessary.

This is a two way traffic through the group transport liaison officers. They tell us what kind of changes they are expecting in regulations. We on the other hand use them to get work done in groups. We say, for example, "All right, if you want higher curie content in your containers, you have to do this kind of work to make a case for it." It is up to them to get the money from their groups and put a modest research program on foot.

Then we have the site movement liaison officers. They are the practical chaps who actually control the movement of radioactive materials from each of our sites. I think there are 14 or 15 altogether. They are essentially practical men, and we do rely on them to tell us how the regulations are reacting on the particular shipments that are going on from day to day.

If I might just carry on for a minute, I would like to say a word or two about the function of the Authority Health and Safety Branch.

We are responsible for producing regulations on movement of radioactive materials for the whole of the Authority. Now, this is something quite apart from statutory regulations that our Ministry of Transport or others will devise. We do this in the form of a Health and Safety Code, which is mandatory throughout the whole of the Authority. It contains our policy goal of basic inviolable principles.

There is a limit to the number of basic inviolable principles you can find. It is supported by recommendations which are the Branches' idea of how you should fulfill these inviolable principles.

Now, it might add a little bit of depth to this if I were to say a word or two about how many packages we are moving at the moment in the UK. The day before I left the UK, we saw the first results of a little census that we are conducting, inspired by the census which the AEC has done. Our figures come up over a six months period to about 41,000 packages. This seems to me to be about 18,000 odd which come from our radioisotope production center at Amersham and about 22 or 23 thousand other packages, mainly fuel element traffic, although I have not seen the breakdown.

By method of transport, I think it comes out something like this: 7 per cent by boat, 10 per cent or a little more by rail, and 28 per cent by air, and 55 per cent by road.

Then I think you have to remember that almost everything goes by road in the first stages. So our road regulations are pretty fundamental. So far as radiation units are concerned, our count is not very good, but it shows that 23,000 of these packages have less than half a radiation unit.

On the curie content we have just done a very rough breakdown on this. We are hoping to get more sophisticated figures, but it looks again as though the bulk of the shipments, that is to say, as many as 24,000, come between 10 millicuries and 2 curies in the content.

I would like to summarize where we have gone in the UK with regulations.

We are really at the moment consolidating our regulations along the lines of IAEA as it was when it came out in 1961. We added a number of extensions to the list. I think if one were to quantify it, it would probably be plus five per cent on what IAEA has done at the moment. But they are as close to IAEA as that.

The first of the new regulations to come to the finishing line, are those for the sea. This has just emerged almost triumphant from this network of committees I showed you. It has only one more committee to go through, and then it will be published. I have put in the back of the paper the differences between these and IAEA.

Our rail regulations are very nearly in the same position as the marine blue book. Through our dangerous goods working party, we are standardizing wherever possible. We want to eliminate the differences between the different forms of regulations in the United Kingdom, differences of phraseology, which although they mean the same thing, when they are passed down hand to hand, the chap who sends the shipment will be confused.

This is really where we think, like charity, compatability begins at home. We have had no trouble at all with our sea and our railways, because these are essentially carrier regulations. They are not statutory regulations, but we run into a lot of trouble with our road regulations that the Ministry of Transport is devising. Our road transport regulations will be statutory. We ran into trouble immediately when we tried to explain to their lawyer what a curie was. In fact, he became quite fascinated when they talked about birds and daughters that were more active than their parents.

So far as air is concerned, we use IATA regulations. We are hoping that IATA will come along on the IAEA bandwagon in due course. If we get a container sent over from foreign countries to put isotopes in and send them back, these containers on some occasions are acceptable by the national airline of the country they come from, but our interpretation of IATA is stricter from other countries. Therefore, when we fill them, we may not be able to send them back because we in the Health and Safety Branch do not think they are safe enough.

Now, IAEA regulations are being revised in March of next year. We are now pressing on with the preparation for this revision. We take it to be a very important revision. We have had two years to see how these IAEA regulations pan out in practice. We have had a lot more time to look at the bases of them and we think this next revision is going to take them one stage further towards being really practical regulations.

We have great admiration for them as they stand now, but they need a little more work on them, and this is no disrespect for those, including our chairman, who took part in framing them. With the little more work which has been done in the intervening two years, we really think these can be made into a first class regulation.

In going into the revision exercise, we are not out to change just for change's sake, nor are we going to suggest changes without giving reasons why. So we have concentrated on producing a series of draft technical reports on different aspects of the IAEA regulations, which are going to be our technical basis for asking for revision.

I would like to list them. I think they are of some interest. The first and by far the most important one is a report which we call "The Transport of Radioactive Materials: Recommendations for the Application of Environmental Testing to the Approval of Packaging." Mr. Messenger is one of the two authors, and Mr. Fairbairn is the other. We have arranged through Mr. Barker for the schedule of test specifications which this includes to be circulated to the symposium.* This does lay down suggested specifications which we are very keen to see in some form or other put into the IAEA regulations.

The second one is a report on the classification of radionuclides for transport purposes and the derivation of activity limits in relation to packaging requirements by Mr. Aspinall and Mr. Fairbairn.

The third is on the control of external radiation during the transport of radioactive materials. This is again by Mr. Aspinall. I am cooperating on it with him.

The fourth one is a paper which Frank Dixon has produced on the design of shielding containment to IAEA standards. I won't trespass on that for he will be speaking to you tomorrow.

This, then, is the way we are working.

Now I want to emphasize here that we would not want to go into the revision (emphasize the revision because I think it is fundamental to the development of IAEA) with national flags flying and drums beating, determined at all costs to push through the United Kingdom's proposals. We would not be going with this spirit at all. We would want to be argued out of them.

In other words, we want to rule out any Quixotic amendment but we are with anybody who can produce work to show why amendments are necessary, and on what basis those amendments should be made.

Our delegation will not be going as a national delegation at all. We will do our very best to subordinate any national tendencies we may have. We are looking forward to a lot of intense discussion.

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*These were distributed Wednesday morning.

Now, I would like to summarize by saying this. Yesterday when we were shown the new labels proposed by the Interagency Committee, Mr. Lowenstein said there were a few head-shakers. I will say that if we in the UK had to choose now, we would go along with this Interagency draft and with the labels that are proposed at the moment. We think it is an excellent job. We like the base on which it is being produced, and give or take five per cent, we would back it up all the way along the line.

I would like that to be made abundantly clear. I summarize with a few fast words.

I really want to emphasize that our aim in the UK is to make use of the International Atomic Energy Agency's regulations. We think there is a great danger that they could be put on a pedestal and for people to say, "These are the magnificent IAEA regulations", and then go on to make their own. This would not be done if the IAEA regulations are clearly preferable and if they can be seen to work. We look forward in that to working with the AEC and with anybody else who may be coming to the Panel meetings from this great country.

DISCUSSION AND COMMENTS

Session Chairman: We appreciate very much these presentations. With respect to the Interagency and International Atomic Energy regulations, we are formulating comments, some of which have already been sent to the IAEA suggesting changes that we would like to see. I think that it is very interesting that the changes which the UK and the U. S. have come up with independently are parallel. We look forward to working together in making the IAEA regulations more practical.

We received very detailed comments from many of you who are sitting in the audience on the "Draft Technical Standards". We are using many of those comments as a basis for some suggested changes. We would welcome any further comments that you might provide to us to use as the basis for revisions, but of course with the appropriate backup material to back up your suggestions.

(Canadian comment) - Sections 6.2.3, 15.2.1 and 15.2.2, and the other sections dealing with fissile materials as well as the Annexes II and III of the IAEA, are considered to be too permissive in Canada. However, there is no objection to the exemptions that are provided in the IAEA pamphlet No. 6. That was the 9 grams of plutonium and 16 of U 233 and U 235. The other sections that the Canadian Committee has some reservations about were that each container, each shipment, each type of shipment should have the approval of the criticality panel. This approval would be good for a year.

(Canadian comment) - The panel at Chalk River had no objection to the technical data presented in the IAEA document. But they felt the Canadian program with respect to fissile materials was small and just starting, and the panel would like to have a hand in on any movement of this material within our country. This can be done in the form of blanket approvals for certain programs, both with respect to processing and shipment. These blanket permits would have an expiration date of one year, and be renewed at that time. Until the traffic in Canada on enriched materials becomes much greater than it is now the panel feels that they should keep their finger in on the types of regulations.

(Canadian comment) - The principal objection in Canada with respect to manufactured items was the wording which has been used: for example, apparatus. This could include a multitude of things that might not be in fact exempt under other parts of the regulations. There seems to be an inconsistency

there. The Canadian Committee thought this section should be limited to certain commodities which would be specifically named, such as electronic tubes. Perhaps by limiting the quantity, the radioactive materials could be incorporated in such specification.

It was noted that the U. S. Interagency Committee has placed some limit on manufactured items. It was suggested that one of the proposals in the UK also put some limit on manufactured items.

Manufactured items usually are considered to be luminous devices, luminous watches, various types of vacuum tubes, and electronic switchboard apparatus that may have some small quantities of radioactive material. Normally this does not include such things as radiography cameras or devices containing several curies. Also, it would include exempt items which move in commerce which are available for sale to the public. One of the requirements is that the radioactive material be not readily dispersable.

It was suggested that some brochures on the purposes of the regulations be prepared for the general public to provide a better understanding of the rules and regulations that are being promulgated. In this particular case as well as in 10 CFR Part 20, AEC people as well as others have difficulty interpreting the various sections. Some sort of explanatory brochure could be very useful.

(UK comment) - I would only add that there is a companion to the IAEA Transport Regulations, "The Notes" in No. 7. In it is a "Child's Guide" which is very useful. We are producing, in the UK, a guide to the regulations intended to be for people actually in the plant. This will take the form of a flow sheet showing, if you have a particular material, you enter into the flow sheet at the proper point and go through this regulation and that regulation and finally you can get out. We believe there is a future for this kind of literal guide to the regulations, and we hope to publish this very soon.

It was suggested that the proposed ICC regulations have one more go-round with the AEC contractors before they are given to the ICC. The contractors had really just one opportunity to comment on these proposals. The new proposals are better, but there are still some contradictions.

(UK comment) - In regard to public relations, we have been very lucky. The public in England is fickle: if you have a Cuban crisis, you could have accidents with radioactive material all over the country and it won't make the front page. If you happen to be on a slack day, then you get it plastered all over the place if you drop a simple isotope. This is a serious problem. This means in fact that our public relations are geared to the maximum possible publicity. We expect the worst whenever there is something. But in general people have taken the regulations very calmly. They have taken the movement of radioactive materials extremely well. We have had very, very little pressure from the general public.

(UK comment cont'd) - The people that we have had trouble with are those that we call minor competent authority, people like ports and airfields, station-masters and people who are somewhere in the chain, and they have enough power to refuse to accept your material, but not enough time to understand what the regulations are about.

In regard to circulating the Interagency draft again, we recognize that it is desirable to circulate and get comments as often as we can. This really could go on for many, many drafts. Of course there are many, many units among the other agencies as well as among the private industry who also desire to comment. Also the rule-making procedure is pretty complex within itself. There is a

requirement that the rule be published for comment under the Administrative Procedure Act by the agency concerned. We will all have another opportunity to comment on the regulations. But at this point we feel that we have a fairly optimum document which we want to get out for everybody to have an opportunity to comment.

Session Chairman: I suppose next to the designer and builder of containers that the next gentleman on our program has the most unenviable job in this area of dealing with standards and regulations in that he has the responsibility of trying to interpret what these writers of standards and regulations mean with all these numbers and figures and words.

Our next speaker is Mr. Al Aikens, chief of the Fuels Processing Branch, Division of Licensing and Regulation.

METHODS AND PROBLEMS IN EVALUATING AND APPROVING CASKS USING SAFETY STANDARDS

by

Alexander E. Aikens, Jr.
Fuels Processing Branch
U. S. Atomic Energy Commission

The Division of Licensing and Regulation requires that the criteria contained in 10 CFR 72 (proposed) be met before a license or approval can be granted for the transfer of irradiated nuclear fuel elements.

Evaluations of the various shipping cask designs which have been performed by the staff of the Fuels Processing Branch have indicated that it is difficult to show conformance with several of the criteria contained in Part 72 due to either a lack of sufficient data or a lack of adequate analytical techniques. It is the purpose of this paper to indicate some of these criteria, against which it has been consistently difficult to assess a cask design. These criteria have been classified into the following three categories:

A. Criteria which have presented basic problems for all cask designers and which will require the data from major testing programs to permit a better analysis.

B. Criteria which have presented difficulties because of a lack of sufficient data which could be determined by relatively simple experiments.

C. Criteria in which an analytical approach is possible, but where performance testing is required since proof of conformance to the criteria is feasible by actual testing.

CATEGORY A

72.32(a) states that the cask, when regarded as a simple beam, shall be capable of withstanding a static load, uniformly distributed along its major axis and equal to 10 times the weight of the cask without exceeding its ultimate strength.

The present method of analyzing the strength of the cask is based on the assumption that the exterior steel liner acts as a thick wall cylinder. This assumption is based on the lead backing stiffening the exterior liner sufficiently to prevent buckling or rupture at a relatively low flexural stress; however, any supplementary flexural strength to be provided by the lead shielding is disregarded in the analysis, mainly because of the weakness of the material in bending under static load conditions.

Up to now, little difficulty has arisen in complying with the regulation, mainly because of the relatively low L/D ratio of the cask designs submitted. The accuracy of the above assumptions is open to question and needs verification, and this will be particularly true in the future if the staff is confronted with cask designs of relatively long and narrow shapes which would have a larger L/D ratio.

Part 72.32(b) states that the cask shall be capable of withstanding an impact force caused by a free fall of 15 feet.

In most cases the analysis assumes that the 60 G's deceleration is applicable and the energy of the deceleration is absorbed by buckling of structural members such as fins, brackets, or crash frames.

The major uncertainties are:

(1) The contribution of the lead shield in resisting the impact on the cask; and

(2) The buckling strength of the exterior structural members for a short duration impact of 16 milliseconds. Very little experimental data are available on buckling strength under dynamic loading.

72.34(a) states that the exterior surface of the cask shall be capable of withstanding a force equal to 30 times the weight of the cask applied over any circular area 6 inches in diameter.

The stated 30 G's force assumed to be applied in 16 milliseconds at uniform deceleration corresponds to an impact force on the cask from a 3.5 ft. free fall on an assumed 6" diameter steel cylinder. The table of thicknesses given in 10 CFR 72 has in general been used as a basis of design. These values were determined, based on an assumed spread of the impact force beyond the 6" diameter circular area, by deforming the exterior liner and taking into consideration the plastic strength of the lead backing under impact conditions. It is permitted to extrapolate this thickness-weight table to include casks weighing in excess of 120,000 pounds by plotting an extension of the data on a semi-log graph. The table thicknesses given have been assumed to be satisfactory when dealing with carbon steel, ASTM A-7 grade, or equal.

The problems in an analytical approach are (1) a determination of spread of the impact area and (2) the resistance offered by the lead backing. Recent tests indicate that the thicknesses given in the table of 10 CFR 72 appear somewhat light for the required 3.5 ft. drop.

72.34(b) Our evaluation of the standard one hour fire is made in order to ascertain whether or not the containment integrity of the cask is adequate. Basically, there are two technical areas into which this evaluation falls, namely heat transfer and structural integrity.

HEAT TRANSFER - The primary purpose of the heat transfer analysis is to determine the amount of lead that has melted at the conclusion of the fire and the resulting temperature distribution that will occur. The approach that has been commonly pursued, is to divide both the one hour duration of the fire and the shielding thickness into small increments, and then calculate the heat input and resulting temperature increase within each increment during the time intervals comprising the one hour duration of the fire. These iterative calculations should determine the quantity of molten lead and the temperature distribution across the cask shielding at the conclusion of the one hour fire.

The difficulties which prevent an analysis of this type from yielding an answer in which the staff has complete reliance are:

(1) The lack of actual data on the rate of heat transfer from the fire to the cask.

(2) The variation in heat transfer rate with time.

(3) The mechanism by which the molten lead transfers heat.

(4) The boundary conditions which prevail at the inner liner during the one hour fire.

STRUCTURAL INTEGRITY - There are three basic methods used to accommodate the lead expansion. This expansion may increase the volume of the lead in its total molten state by as much as 10%. The relief of this volume increase is accommodated by:

(1) controlled voids in both the cask body and the lid;

(2) normal expansion of the exterior liner due to the elevated temperatures reached in the one hour fire condition; and

(3) abnormal expansion such as bulging of the exterior shell which is caused by the hydrostatic pressure of the molten lead and the additional pressure due to volume expansion. The distortion will very often exceed the elastic limit and therefore the cask will not return to its original shape.

Generally, the designs take advantage of a combination of the three occurrences. Our evaluation usually concentrates on the integrity of the outer shell to prevent exceeding its ultimate strength. Although it is normally assumed in the analysis that the welds are as strong as the liner, the assumption is open to question since it is known that stress risers occur in weld areas. In order to determine the probable areas of inadequate shielding which may occur after the cask has cooled down, it is assumed that all void spaces are filled with lead and that only the thermal and elastic expansion of the exterior liner will have rebounded.

One of the major problems which occurs in an analytical structural analysis during the one hour fire is a determination of the actual void space that will be available to receive molten lead and thereby properly relieve the pressure.

It is hoped that the fire tests which are now in progress or being planned, will furnish the necessary information to clarify the heat transfer and structural integrity problems.

72.38(a)(4) states that the failure temperature shall be considered to occur when 100 curies of beta-gamma or one curie of alpha activity is released to the primary coolant.

At the present time there are no reliable methods of calculation which can determine the temperature at which a fuel element will fail. Some applicants have suggested that the melting point of the cladding be used as the failure temperature. Obviously, this is an upper limit and unless it can be experimentally proven, it will be seriously questioned during our evaluation. Other applicants have submitted failure temperatures which have been backed up by the reactor manufacturer's experience with the particular type fuel element. Still another approach that has been used, is to calculate the amount of gas

that has been produced in a fuel element during its irradiation period. Using this calculated amount of gas, one can then calculate the pressure and its subsequent stress on the fuel element cladding as a function of temperature. Having determined this stress versus temperature relationship for the fuel element, one can then determine the temperature that a fuel element must reach in order to exceed its ultimate strength. The difficulties and uncertainties in this type of an analysis are:

1. How much gas will be generated in the fuel during irradiation?

2. What fraction of this generated gas will escape from the fuel matrix and occupy the void space between fuel and cladding?

3. How much void space is there between the fuel and cladding?

4. How accurate are the calculations relating temperature and pressure of the gas to the stress that will be set up in the cladding?

5. How does this ultimate strength of the cladding normally vary with temperature and what effect has irradiation had on the relationship?

CATEGORY B

72.34(n) states that each cask vent or pressure relief device must be equipped with a filter capable of removing at least 99.9 percent of particles $\geq$ 0.3 micron in size. In order to prove compliance, calculations should be submitted showing the maximum discharge rate and how well the filter assembly will operate under these conditions.

72.34(g) states that the cask should be capable of withstanding vibration incident to shipment. Little or no information has been submitted on the amplitude and frequency of vibration that a cask might encounter during shipment. Therefore, analyses showing that the cask's integrity will not be impaired from vibrational effects are not normally performed and it will be necessary to get data during the course of actual shipments before they can be performed.

72.38(a)(2)(ii) states that any liquid coolant must not freeze under the most adverse weather conditions anticipated, therefore antifreeze has been used in many casks when the likelihood of freezing has occurred. The problem which we have encountered with the use of antifreeze is, "What are the effects of the gamma irradiation on the antifreeze"? Some of the common antifreezes, such as ethylene glycol, have shown adverse effects from irradiation, and unless an antifreeze has shown satisfactory performance under irradiation, it will not be acceptable.

72.34(j) states that valves, piping and other external parts should be protected from any mechanical damage to be anticipated during normal handling and transport. Since the types of accidents that can occur are unknown, we normally and arbitrarily require at least a 1/2" steel cover plate around protruding fittings to prevent damage which could result in dose rates greater than 1 r/hr at one meter.

72.38(a)(3) stipulate that the temperature of any fuel element must not
72.38(b)
exceed either (1) 300°F (2) the maximum temperature attained during its irradiation history or (3) 300°F below its failure temperature under normal

conditions of transport and 200°F below its failure temperature for a loss of coolant accident. The calculations that must be performed to determine the fuel element's temperature for the normal and loss of coolant conditions may become extremely difficult due to the complexity of the fuel assembly array, however the fuel failure temperature is even more difficult to calculate as we have previously discussed.

CATEGORY C - The analytical methods which have shown compliance with several of these criteria have on occasion presented difficulties to the reviewer. These difficulties have usually manifested themselves due to the applicant's assumptions in his analysis. In many of these cases, one can argue that if a more conservative analysis were performed, conformance with a particular criterion would not have been achieved. However these criteria must be proven by actual performance tests, regardless of the result shown by the analytical approach.

72.35(a) states that the external radiation level must not exceed 200 mr/hr at the accessible surface or 10 mr/hr at one meter from the surface or 10 mr/hr at 3 meters from the surface when the cask has exclusive use of a transport vehicle. The calculations necessary to show compliance with this criterion are relatively straight forward, however there are uncertainties in such variables as the source strength, the energy spectrum and the geometric model to be used.

72.35(c) states that the shielding must prevent beaming of radiation to the exterior of the cask. This criterion is best verified by radiation monitoring of the cask's exterior surface with the actual fuel loading in place, since it is difficult to determine all of the passages which the radiation might follow.

72.38(a)(1) states that any easily accessible surface of a cask must not exceed 180°F, however if in contact with dunnage, the temperature cannot exceed 350°F in land transport or 180°F in water transport. The calculations which are performed to show compliance with this criterion are subject to certain assumptions which may be in error to a degree. These assumptions are:

(1) Actual decay heat load

(2) Effective heat transfer surface area

(3) Emissivity of the cask's surface and

(4) The heat transfer coefficient between the cask surface and the atmosphere.

72.38(a)(2)(iii) states that the temperature of any liquid primary coolant must remain 20°F below its boiling point. This calculation is subject to the same errors as in 72.38(a)(1) since the cask's surface temperature must be known. In addition, there are cases where the primary coolant's flow pattern is difficult to determine and therefore the heat transfer coefficients that should be used.

72.38(a)(2)(v) states that the gauge pressure of the primary coolant must not exceed 50 psi or 50 percent of the cask's design pressure. Since a determination of the cask's operating pressure depends on the equilibrium temperature attained by the coolant, this criterion can only be accurately assessed when the results of the heat transfer performance tests are known.

72.38(a)(2)(vi) states that any cask with a mechanical cooling system should be provided with a back-up mechanical system unless failure of the first

device will result neither in a rise of 100°F nor an increase of pressure beyond 75 percent of the design pressure. Performance tests are needed if a mechanical back-up system is not provided, because casks requiring mechanical cooling systems usually have high heat loads and complex fuel arrays which are difficult to analyze as previously discussed.

Although the criteria in Part 72 do not require quality control, we feel that this is one of the most necessary requirements in assuring the design of a safe cask, since strict adherence to the specifications is the only assurance of safety.

For example we believe that the following should be verified:

1. Material quality.
2. Dimensions of structural components.
3. The fit of mating parts.
4. The adequacy of seals and fittings.
5. The qualifications of welders.
6. Quality of welds.
7. Pressure test and leak tightness of subassemblies.
8. Bonding of lead to cask shell and
9. The adequacy of lifting trunnions and attachments.

Session Chairman:
Our next speaker, Mr. John Langhaar, Atomic Energy Division of DuPont, has spent considerable effort on the problem of developing standards for shipping fuel elements.

PROBLEMS IN DESIGNING CASKS TO MEET REGULATORY STANDARDS

by

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The problems of designing casks to comply with the regulations stem primarily from a lack of knowledge and data, with the result that designs in which we are highly confident incorporate conservatism of unknown magnitude and cost. We know how to produce acceptable casks if cost is of no concern. For example, the amount of fuel in a cask could be limited to a point where there would be no question about heat removal or criticality, and the size of casks could be limited to a point where crash shields of proven design could be applied. The investment and operating costs would be high, and probably not consistent with the generally accepted values and risks in other areas of human activity. It is conceivable that conservatism could be carried to a point where the personal injury and property damage resulting merely from shipping the large amount of lead and steel would greatly exceed the injury and damage resulting from escape of radiation and radioactive material.

One important function of the cask designer is to produce the most economical acceptable design. In general, when a sufficient amount of fuel is available for shipment, capital costs and operating costs are reduced by increasing the amount of fuel in the cask. At present, an upper limit of 75 to 100 tons for the loaded cask weight is imposed by the available handling and shipping facilities, although this limit may be extended in the future.

But here several technical and engineering problems arise, and it is these that we shall consider in more detail. In order to minimize cost and at the same time have a high degree of confidence in compliance with the regulations, it is important to have data and methods for reliable prediction of the behavior of fuel and cask. For several requirements of the regulations, engineering knowledge is at present inadequate.

We shall consider one by one the most troublesome paragraphs of 10 CFR Part 72, and at the same time point out certain difficulties of interpretation. The remarks relate principally to casks using lead as a shielding material. Some of the uncertainties could be avoided by using solid steel; however, to the best of my knowledge, no large solid steel cask has yet been built. It is possible that fabrication would be difficult and costly, particularly if stainless steel surfaces are required. The advantage of lead which has been responsible for its general use for large casks is the lower weight for a given cavity size and shielding value. The energy ab-

sorption properties of lead may be advantageous from the standpoint of damage to fuel under impact conditions.

Paragraph 72.32(a) requires that the cask as a simple beam should support ten times its own weight without exceeding the ultimate strength. Since customary stress calculations based on elastic theory are not applicable for stresses exceeding the elastic limit, the rigors and uncertainties of plastic type calculations, perhaps together with the cost of experimental work, would be encountered if it were desired to design for stresses close to the ultimate strength. For those casks with which I am familiar, however, the other strength requirements result in a structure which easily meets the beam strength requirement. Some other countries have considered requiring greater beam strength, even up to 500 times the weight of the cask. This would introduce serious and perhaps insurmountable problems for a long cask; however, the justification for such large numbers will undoubtedly receive careful study.

Paragraph 72.32(b) requires withstanding a flat drop of 15 feet onto an unyielding surface without exceeding the ultimate strength of any structural portion of the cask and without a resulting radiation level greater than 1 r/hr. at 1 meter. The words "without exceeding the ultimate strength" are taken to mean "without rupture". Also, a "structural portion of the casks" is taken to mean a part which, if ruptured, would permit loss of shielding so that the resulting radiation level would exceed 1 r/hr. at 1 meter, either before or after a fire.

How can we predict whether or not rupture will occur? It is manifestly impracticable to perform tests with prototypes of each proposed design, even if we assume that the properties of a hypothetical unyielding surface can in some way be simulated. Several prototypes of each design would be required, for the drop tests in different orientations. If rupture occurred, there would still be uncertainty about the extent of change necessary to avoid rupture.

Prediction by calculation is another approach. Discussion of this problem with a number of stress analysts has led me to believe that because of inadequate experimental data, only a very low order of reliability could be attached to such calculations. That is, for a cask that would nominally just withstand a 15 foot drop, the 95% confidence limits might be 10 feet to 30 feet or 5 feet to 50 feet, for example. Actually we have no sound way of assigning confidence limits. The difficulties include lack of data concerning physical properties of the materials under impact conditions; lack of knowledge concerning shock waves, stress concentration, and other characteristics of a cask structure; and the complexities of the mathematics. A purely analytic procedure, using only what is normally considered basic data, appears not feasible in the foreseeable future.

Now Part 72 does permit the alternative of considering a 60 g force for not less than 16 milliseconds, rather than a 15 foot drop. Some research work has been done to determine the effect of duration of applied force for relatively simple systems. Methods of taking the time element into account for a complex structure such as a cask have not been developed, although it is safe to say that a long time is more severe than a short time.

Even if we assume the 60 g force to be of indefinite duration, however, our troubles are not over. If calculations are based on elastic theory, a calculated stress exceeding the ultimate strength does not support the conclusion that rupture would occur. For stresses exceeding the elastic limit, actual stress in general is lower than calculated elastic stress,

since yielding of the material tends to relieve the stress. Thus for a design close to the regulatory limit, plastic-type calculations should be used. Here again, available data are inadequate.

As an example of the amount of uncertainty in basic data, the flow resistance of lead under impact has been taken as low as 800 psi and as high as 12,000 psi by different stress analysts. The lower figure is commonly accepted as the approximate yield strength under slow strain; the higher value is suggested as an impact value in Goldsmith's book on impact. The actual value in a particular case may depend strongly on rate of strain, degree of confinement, temperature and other factors. It is important because a large fraction of the impact energy appears to be dissipated in flow of the lead, and the amount of lead displaced is in inverse proportion to its resistance.

Another approach, and one showing considerable promise, is testing of models. It is possible that for a reasonable cost enough models of different size and shape can be tested to provide a standard series and to provide a reliable indication of size-effect. A proposed cask might then be compared with this series, or in some cases additional testing might be required. The effect of minor variations in design could probably be calculated with sufficient accuracy after the establishment of further basic information on the properties of the materials.

Model testing should probably include protective devices of various types, such as I-beam frames and Hanford-type buffer systems. The cask designer might then be in a position to select something approaching the optimum combination of cask and protective device.

As most of you know, fundamental work toward this goal has been done during the past year under the auspices of the AEC, through Oak Ridge, Savannah River, Hanford and the Franklin Institute. Much more remains to be done, however, to place this method of prediction on a firm footing and to cover a suitable range of variables.

Paragraph 72.32(c) requires that the lid fastening be capable of withstanding a force of 60 times the weight of lid plus contents, for a period of 16 milliseconds without exceeding the ultimate strength. The problems here are similar to those described for the preceding paragraph, but the penalty for conservatism is not so great. An acceptable solution in most cases is the application of a static analysis of the elastic type.

Paragraph 72.32(d) requires withstanding an internal pressure of twice the operating pressure but not less than 20 psig without exceeding the yield strength. Calculations are reasonably straightforward, although questions have arisen regarding whether the closure, which might include a gasket, should be leaktight at this pressure and whether external attachments such as expansion tanks, filters, etc. should resist this pressure. A questionable situation should of course be reviewed with the AEC, although for preliminary concepts the designer may be guided by the observation that the primary purpose of the requirement is to assure ruggedness of a certain type perhaps not provided by other requirements, sc as to reduce the likelihood of radiation exposure in an accident.

Paragraph 72.33 regarding the integrity of fuel element holders, structural poisons, and internal containers does not specify the forces. A certain amount of individual judgment is required; however, it would seem that ordinarily there will be no great difficulty in providing an acceptable design.

Paragraph 72.34 specifies resistance to a certain penetrating force or alternatively complying with a given table of thickness for the exterior surface. The uncertainties of calculation are such that at the present time it is preferable to resort to experimental work or else follow the table. Just what constitutes the exterior surface in some cases is questionable. Credit might sometimes be allowed for external fins and other attachments, a surrounding crash barrier, and even parts of the vehicle. There is also some question about how to treat a surface of varying thickness, for example, a surrounding barrier with gaps or perforations.

For casks having a shielding material with melting point lower than 1000°F, paragraph 72.34(b) requires that the shell must not rupture if the cask is exposed to a standard one-hour fire. Since accidental conditions other than the fire are not specified, it is assumed that the cask is initially in its normal position with normal coolant present.

Methods of shielding the cask against the major effects of fire are possible, although to the best of my knowledge there has not yet been demonstrated a low-cost method which does not introduce problems of heat removal from the cask. With unprotected casks, in cases which we have examined, it has been concluded that much or all of the lead would melt. How to accommodate the expansion of the lead, to the extent of 10% or more, is a problem particularly with casks of a cylindrical shape. The use of controlled voids sounds plausible; however, a British report states that trials of this method with small containers have thus far been unsuccessful. It appears that the lead does not necessarily melt first in the region of the voids.

Strength is very low for carbon steels at about 1200°F and for stainless steels at about 1500°F. The standard one-hour fire has a temperature above 1500°F for more than 30 minutes. The specified fire temperatures are the readings of thermocouples arranged in a particular manner; actual flame temperatures are reported to exceed 2000°F. It is therefore important to estimate cask temperatures with reasonable accuracy in order to determine whether the steel will rupture as a result of lead expansion and liquid lead pressure.

Actual testing of various casks would be very costly, and we are led to believe that except for certain basic data tests of models cannot be satisfactorily extrapolated to full size casks. Calculation, which can best be done by computers, seems to be the only alternative. Information not now available is required concerning flame temperature, flame emissivity, and other characteristics of the fire. Cask surface absorptivity and emissivity are also important. Possibly values of the parameters could be suitably established by comparing calculated and test results for a small number of casks.

The maximum amount of fuel in the cask will in many cases be set by paragraph 72.38(b), which requires that in the event of loss of coolant the fuel temperature will not approach failure temperature closer than 200°F. Reliable prediction of failure temperature, which must be based on experimental work with irradiated fuel, has so far generally not been possible. For metal clad fuel, an estimate that is probably conservative can be made by assuming all low boiling point materials to be free, and calculating the corresponding cladding stress. This may be unduly conservative for some aluminum-clad fuels, in view of the fact that aluminum has a low melting point and fission gases are not entirely free. Furthermore, rupture of cladding at a low temperature is not necessarily accompanied by release of enough activity to warrant classification as a failure. Some experimental

studies with metallic fuels have indicated little release other than gaseous fission products at temperatures below the melting point. Further laboratory work may be justified to develop basic data on rates of release and rates of diffusion of activity for fuels of different composition.

Accurate calculation of the actual temperature attained by the fuel is practically impossible for many fuel arrays. Factors having an important effect include surface characteristics of the irradiated fuel, extent of contact of fuel with heat conducting surfaces, and extent of air circulation within the fuel array. The performance of suitable experiments with irradiated fuel has not been done because of the hazards, and also because commonly a sufficient quantity of irradiated fuel is not available at the time of cask design.

Avoiding the escape of a large amount of activity in the event of loss of coolant is admittedly important. The economic significance of this requirement would seem to warrant a study program to accumulate data and develop methods for estimating failure temperature and actual fuel temperature. Perhaps such a study should include also consideration of the probability of occurrence and consequences of activity release, in order to indicate how accurate the estimates should be and how confident we should be that in an actual incident the limits would not be exceeded.

With normally dry shipments, these uncertainties represent a normal state of affairs, and the margin of safety should be taken into account accordingly. Ordinarily the calculation of normal fuel temperature with liquid coolant can be performed with acceptable accuracy, although there is some question about the intent of paragraph 72.38(c) with regard to diurnal and seasonal variation of ambient air temperature and solar radiation.

Other aspects of compliance with the regulations without large economic uncertainties have, as far as I know, not involved any serious problem.

In summary, it appears that designing casks for minimum cost within the limits imposed by the regulations requires the accumulation of much more experimental information related to damage from impact, characteristics of the standard fire test, release of activity from fuel at elevated temperatures, and expected fuel temperatures after loss of coolant.

Remarks by Mr. Langhaar: For the past several years, I have been straddling the fence in the morass of cask design, on the one hand promoting strenuous safety requirements, on the other hand pointing out how difficult it makes the life of the designer and how much it costs.

I believe playing this dual role is not inconsistent. We all agree that high safety standards are required. Unfortunately we do not have the numbers to plug into the equation that Dr. Leimkuhler has referred to, which would attempt to strike the proper balance between the conflicting interests of safety and economy. As a result, there is not always agreement on whether a particular requirement is too stringent or too lax.

Fortunately for the cask designer, he is not faced with the problem of deciding whether a particular requirement is too stringent. This decision has been made for him. It is spelled out in the regulations.

What I want to talk about today is the problems that the designer is faced with in attempting to comply with these regulations. First of all, we must assume that a high degree of confidence in compliance is required. My viewpoint is that we cannot predict anything with 100 per cent assurance, but we can have a high degree of confidence, for example, 99 per cent, 99.99 per cent, that a cask and a particular feature does comply with the intent of the regulations.

Now that we do know how to design casks that comply with the regulations with a high degree of confidence it is possibly of no concern. For example, we could ship a single element in a fuel cask, an element emitting a specially small amount of heat, so that heat dissipation is no problem, cirticality is no problem. The cask is small enough so that it can be enclosed in a bumper system of reliable design. The cask could be protected with some sort of insulation material or other heat barrier to withstand fire. This would all be very costly, but it would be a design in which we would have a high degree of confidence.

The problem of the cask designer then is trying to narrow down the limits or improving the reliability of the design so that he can design close to the limits of the regulations with confidence and produce an economical design.

In general the economics are improved by increasing the size of the cask. That is the investment per fuel assembly and the operating cost per fuel assembly are in general reduced by increasing the size of the cask.

There is an upper practical limit to the size of the cask nowadays in the neighborhood of 100 tons. This is determined by the transportation facility, but that limit may be extended in the future.

Now, in designing large casks, the knowledge and methods of analysis are at the present time inadequate for design within close limits that we would like to have. I will discuss the principal inadequacies of our knowledge and data with respect to regulations.

As you might expect this will overlap to some extent what Al Aikens has already remarked upon, the problems faced by the person designing the cask and the problem faced by the person in deciding whether a particular design complies with the regulations are very much the same. These comments will apply primarily to lead filled casks.

Solid steel casks are being promoted in some quarters, particularly because of more reliable resistance to fire, or, let us say, more predictable performance

in a fire and perhaps solid steel casks have some advantage from the standpoint of strength. However, I have had no experience, myself, with such casks. I am not aware that any very large solid steel casks have been fabricated. So I don't know what the problems may be or what the costs may be.

Now, the first of the major problems that I would like to mention is the problem of designing so that the ultimate strength is not exceeded. The ultimate strength is referred to in several paragraphs of the regulation and in particular a simple beam requirement, that the cask must withstand 10 G's without exceeding the ultimate strength. The drop test at 15 G's force without exceeding the ultimate strength of any structural part of the cask. The fastening must withstand the force of 60 times the weight of the lid plus contents. The cask must withstand a 30 G force applied over a six inch diameter area without exceeding the ultimate strength of the shell of the cask and must also withstand a one hour fire.

How do we determine whether or not the ultimate strength will be exceeded or whether rupture will occur? The customary method of calculation is the elastic theory of calculation which is valid only for stress below the elastic limit. A calculated stress, calculated in this manner, exceeding the ultimate strength, does not necessarily indicate the rupture will occur. It indicates that deformation will occur and deformation relieves stresses, so that the actual stresses might be considerably beyond the ultimate stress.

In order to make a meaningful calculation the deformation will have to be taken into account at the site for which we don't have the necessary knowledge and method for the construction of the complicated casks. It is complicated enough for a single beam.

A further complication would be the time element specified in the regulation, 16 milliseconds which is specified by impact with the lid fastened and for the penetration.

Now, what is the value of this 16 millisecond duration? I have recently learned of some work which has been done at the University of Texas to determine the effective duration on deformation. This work has been done with very simple systems through the manual system, I believe primarily the cantilever beam. Even with this simple system, the work has been rather complex, the experimental work, and as expected, it has been found that a force of short duration may be much greater than a force of long duration, without producing deformation. However, such results and such information cannot be applied at the present time to anything very complex, certainly nothing like a cask.

Now, what we must do, what we have been doing, is assuming the force will be of indefinite duration. Now, with all these complications is it feasible to make the calculations? I would say no, at least for some of the requirements of the regulations the calculations are worthwhile, because if the calculation based on elastic theory is less than ultimate strength, then we can be pretty sure that the actual stress will be less than ultimate strength. This condition exists or can be made to exist at a moderate cost penalty for some of the requirements, particularly for the beam strength requirement and for the lid fastening and sometimes for fire resistance, although there are more serious problems than fire resistance which I will get into in a moment.

So calculations do serve a purpose for those particular requirements.

Now, stresses from impact on flat surface of six inch diameter cylinder cannot be brushed aside so lightly. We are forced to consider other alternatives.

Another alternative to calculation is full scale testing. Full scale testing of all casks is prohibitively expensive and impractical. Several prototypes of each cask would be required in order to obtain really useful results. However, testing a small number of casks is feasible and not too costly. It may be done in order to establish a scale of factors for our models, which leads me into the next alternative, model testing which looks very promising. You will hear more about this from Harry Clarke.

Such model testing has been going on at Oak Ridge, Savannah River, Franklin Institute. It appears so far there is good correlation between the deformation and damage suffered by models and that suffered by a full scale cask. The program of model testing I would think would include such variables as shape, shell thickness, temperature, use of protective devices such as I-beam frames, buffer systems, in order to establish what we might consider a broad range of variables for the designer of a new cask, so that he might fit this design into the series somewhat, and with a fair degree of confidence, decide whether his cask will meet the requirements.

Now, minor deviations from this model series could be perhaps taken into account by calculation although even for a calculation of the effect of these minor deviations we need more information.

It appears that the energy method of calculation would be more useful for this purpose. I may mention that force times time is not a measure of energy, but the 15 foot drop or force times distance is force times distance, a measure of energy. We must use the 15 foot drop or some other drop specified and calculate the way in which it is dissipated; calculate it after observing some testing of the full scale model.

Now, some information we need for reliable calculation of even these minor effects include the nature and displacement of the steel, flow resistance in the lead, the effect of lead bonding and perhaps other factors that may be found to be important.

The degree of uncertainty that exists in this field I may illustrate by referring to the flow resistance of lead. I have seen calculations by different stress analysts who have used figures variously from 800 pounds per square inch to 12,000 pounds per square inch as the flow resistance of lead. It is somewhere within that range.

Now, this is important, because it appears that a large part of the energy in the drop is absorbed by displacement of lead and the amount of lead displaced by the amount of energy absorbed is inversely proportional to its flow resistance. If we don't know that within a factor of ten, we are in bad shape.

So much for the ultimate strength. The next major problem is the fire resistance which is three problems. One is determination of the temperature. Second is the determination of the amount of deformation and stresses that exist in the structure from the expansion of the lead. Third is the determination of stresses from the thermal effect and from the pressure head of liquid lead in the shell and we might add a fourth, the determination of radiation levels in the vicinity of cask after fire.

The determination of the temperature throughout the cask is important for this reason, that flame temperature in the standard fire is reported to exceed 2,000 degrees Fahrenheit. The temperature as measured by thermocouples is up to 1700. Carbon steel has lost most of its strength at 1200 degrees, stainless steel at 1500 degrees. So you can see that a cask in a flame of 2,000 degrees

may have shell temperatures of close to 2,000 degrees, and have no strength to speak of. So, determining shell temperature is important, and at the present time we are not in a position to calculate this within a matter of several hundred degrees.

Model testing I am led to believe is not practical. It is not feasible to extrapolate model results to full scale results. The alternative here may be testing of a few full scale casks in order to establish values of the parameters that are required reasonably for reliable calculations, and in particular as Al Aikens mentioned a short time ago, things that we need to know for reliable calculation is the flame temperature for which we have a little bit of information, flame emissivity for which we have no information, cask absorptivity and there may be others.

Now, in the second fire problem, where does the lead go when it expands and what stresses does it produce? In the case of a rectangular cask we feel fairly sure that the expansion of lead will be accomodated by deformation of the walls. The walls will bulge in and bulge out and they can do this without being very highly stressed.

In the case of a cylindrical cask, this is a horse of another color. It is possible that expansion joints can be built into the structure or the cylindrical shell can be designed so that it will accomodate expansion. So far as I know, these methods have not been demonstrated.

Another possibility that has been suggested, and is being used is controlled voids.* How well the voids are controlled we don't know. There is a British report which states that on the basis of some tests with small size containers that attempts to provide for the expansion of lead by the use of control voids has been unsuccessful. This is apparently due to the fact that the lead does not necessarily melt where the voids are. First, it would melt somewhere else. So I think this is an area where further study is necessary, how to accomodate the expansion of the lead.

Now I am going to suppose that the expansion of the lead does not produce unduly high stresses in the shell and that hopefully then in most cases elastic type leads will be satisfactory, and will show stress less than the ultimate strength at the calculated shell temperature. If not, then the designer may be faced with one of the alternatives, either resort to complexities of elastic type compilations or modify his design to be more conservative, or perhaps resort to model testing for stresses which is different than the model testing for temperatures. Or perhaps provide in the cask some sort of protective system, some sort of protective heat barrier. One type of heat barrier that has been suggested is paint which at temperatures of three or four hundred degrees Fahrenheit will foam and provide insulation.

Other heat barriers to protect the cask from radiant heat might be used. It is also possible that shipping the cask in a tank of water would meet the present requirements of the regulations which do not specify any other accident at the time of fire.

However, all of these methods require further study to determine the effectiveness, the problems that may exist from heat, contamination, other operating problems which may exist. For example, it might be desirable to have strippable paint in order that the cask may be suitably decontaminated before shipping. It might be desirable to have a washable type of paint so that after a fire,

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* Referring to work reported by F. Dixon in the Symposium on 5 December.

after it has foamed, it will wash off and not impede the normal escape of heat from the cask.

The final fire problem that I want to mention is radiation levels. It appears to me that the radiation levels at the present time are not known within a factor of a hundred, because we don't know where the voids are going to occur on cooling of the cask. I can visualize moderate cost methods of providing for shrinkage of the lead if the cask is presumed to be in a normal position. So far I have not been able to visualize any good method of providing for this shrinkage if we must assume the cask will be in any position.

Another consideration in the fire analysis which may be particularly serious is the head of pressure developed by the liquid lead if large amounts of the lead do melt. The atmospheric pressure could counterbalance that head of liquid lead only about three feet. In a cask eight feet tall, for example, if the shell were plastic or rubber on the bottom, it would stiffen on the top. The lead would settle down to a height of three feet and have a perfect vacuum above it. This would not be good from the standpoint of radiation levels.

On the other side of the picture, I would like to make this remark, that high radiation levels after a fire may not represent any particular hazard to the public and therefore may not be of great concern from the standpoint of these regulations, because certainly during the fire the public would be excluded from the area, and after the fire probably would be kept away.

The final major problem that I would like to say a few words about is the one assuring in the event of a loss of coolant the temperature will remain 200 degrees Fahrenheit below the failure point of the fuel. One is determining failure temperature, and the second estimating the actual fuel temperature. This is very often an important limitation. That is, this requirement limits the amount of fuel that may be carried in the cask. Failure temperature which is defined in terms of activity of release might be determined experimentally with irradiated fuels although there are many experimental difficulties and it would be a rather costly procedure.

Also, normally the design of the cask should proceed before quantities of irradiated fuel are available for such experimental work. Al Aikens has mentioned what assumptions are now being used for estimating failure temperature. He has pointed out this is largely conjectural. We really don't know failure temperatures of most fuels within several hundred degrees. This is unfortunate from the standpoint of economy of design. With aluminum clad fuels of the type commonly in use today it seems likely to me that the failure temperature is not below the melting point of cladding and in fact may be considerably above the melting point of the cladding, although by regulation we must assume that it is not above the melting point.

The stainless steel clad fuels, the customary assumption for calculating failure temperature has been outlined. Some work has been done which indicates if the temperature is below the melting point of the fuel, the loss of activity is not very great, except for the gases.

So it may be that the actual failure temperature is considered higher than the calculated temperature. Maybe in connection with the failure temperature we should also take into account the possibility that in the future there may be unclad fuels so that the reference to cladding is of no consequence.

Determination of actual fuel temperature is difficult, and particulary where we don't know the degree of contact between fuel assemblies. We do not know the manner in which the radiation has certain characteristics of the fuel.

Experimental work has not been done in this field, because of the hazard and cost of doing such work with irradiated fuel. It may be that some work is feasible, that, at least, will give us a better feel for fuel temperatures.

To summarize these remarks there are many uncertainties in our data and in our calculations so that we are not in a position to design closely regulatory limits to confidence. As a result our costs may be considerably higher than would be required if we had any following, maybe twice as high or three times as high. It is also possible that in some respects we think our casks comply with regulations when in fact they do not. Areas which would seem to deserve further study include these, the principal ones: damage from impact, determination of the characteristics of the standard fire, the accomodation of lead expansion, and the avoidance of voids in undesirable locations after having the fire.

The greater activity release from fuel at high temperatures and perhaps diffusion information, and also determination of actual temperature of the fuel after loss of coolant are also uncertainties.

DISCUSSION AND COMMENTS

The GE Vallecitos Laboratory has been shipping irradiated GTR fuel now for about a year and a half. An AEC license was obtained about a year and a half ago, and complied with the 10 CFR 72 proposed at that time. However, there was no fire test in 10 CFR 72 then.

The details of the ASTM test now referred to in 10 CFR 72 contains a certain amount of ambiguity. In particular, as to where the temperature is to be measured. One could measure the temperature of the surface of the cask or a portion of the oven in which the test is being made.

In the licensing review, it is assumed that the cask has been placed in an atmosphere which shows the temperature specified in 10 CFR 72.

It appears that at 1700° Fahrenheit at several hours the shell will not have the tensile strength to support the weight of the lead.

Lead in the molten state requires approximately 10 per cent expansion of lead volume. Using a controlled void is a very problematic thing, because you don't know if the lead is going to melt in the area of the void and get into the void.

Perhaps this could be arranged by having openings into the void which, under the increasing stress of the molten lead, would allow some of the lead to flow into the void.

(UK comment) - Just two small points in connection with Mr. Langhaar's paper. There is in fact a steel flask in existence which weighs about 50 tons, and is used for transporting the spent fuel from the Central Electricity Generation Board reactors to the processing plant. There is also a paper presented at the UK Symposium in October dealing with a similar flask which was originally proposed to be in cast iron, but could be in cast steel, similarly dimensioned, but not actually used.

(UK comment)
We feel it is wrong to treat the fire as a maximum credible accident in itself. We have used, and I think there has been general agreement, the concept of a severe impact accident of some kind, followed by fire, as would happen if you had a rail accident involving a train of tank wagons. For that reason you cannot assume that the flask will be in any particular orientation when it is in the fire. You must consider all possible orientations.

The design of very large shipping casks, maybe 125 tons in nature, makes it very expensive to subject one to any fire test in an oven. Conservative calculation, say, such as those on the IBM 790 program, showing these temperatures not to be in excess, have been accepted to demonstrate compliance with the regulations. I don't know of any cask that has actually been subjected to a fire test to show that it conforms.

Painting containers is a good idea. One container made of stainless steel has been difficult to decontaminate. It has the appearance of being sand blasted. We have proposed this be painted and I have had some information that some areas will not accept painted spent fuel shipping containers.

There is lack of agreement among various facilities on the relative merits of painted and unpainted containers. The viewpoint expressed a couple of years ago by representatives of Hanford, Oak Ridge, Idaho and Savannah River, at a meeting where this particular subject came up, was that stainless steel surfaces, even sandblasted stainless steel surfaces, were preferable to painted surfaces. Other people have expressed different views. In particular we have a different view from Chalk River where their experience has been better with painted surface. Sand blasted stainless steel surface may be a little bit rough whereas the painted surface is smooth. The main problem with painted surface is maintenance. If the paint film is continuous, the surface can be well maintained. It is probably a good type of surface for decontamination. It can be removed fairly readily in the event decontamination becomes difficult. However, often the paint was not maintained as it should be maintained. There would be some areas without paint that rusted and it would be very difficult to decontaminate. Also there were breaks in the continuity of the paint film and contamination would get underneath.

It is about a toss-up between these two systems.

The comment was made that we do not have a standard fire in transportation. The severe fire such as we might have with a tank car is a fuel type of fire, and the fuel is not what burns. It is the vapor. As the fire progresses, all of the fire gets pretty well up in the air shortly after it gets under way, so that the extreme heat, is not around the containers. In other words, the tank cars are not melted down after they have been in a fire. So we are not quite so concerned as some with a fire in transportation giving a prolonged and extended period of heating to the container.

Now, the transfer of heat through lead is quite good, I believe. The shell would have to be very hot before it began to weaken very much. By the time it is that hot, the elasticity of steel has changed considerably. So that regardless of the shape of the container, it seems reforming of the container would take care of the expansion of the lead in the kind of fires we have in transportation.

I am not talking now about a test fire that you might be able to build. If the consensus is that I am wrong in this opinion, I think the Bureau of Explosives should discontinue approving containers for this purpose until such time as design detail can be worked out to show that all of the requirements that have been proposed can be met.

10 CFR 72 contains criteria for a fire. We cannot overlook the fact that a fire may occur and the cask melt down.

It was suggested that the standard fire test be a flammable fuel fire test with the container in the middle of it out in the open, which is the condition you get in transportation. The standard fire test was designed for safes

in buildings where the fire burned up around the material. It may be on the 10th floor and we do not have standard fire in accidents in transportation. Perhaps some test other than the standard fire test should be looked into.

This question is one which occurred in the American Standards Association group, too. On checking with Underwriters' Laboratories as to their opinion on the reasonableness of this one hour fire test for a transportation accident, they reported that this standard one hour fire test was developed to simulate a building fire, and maybe a safe in a building. They thought the temperatures and conditions, however, were reasonably representative of what we might expect in a petroleum type fire on a railroad siding.

Regarding whether or not we can meet the fire test, I think we have a fair degree of confidence that many of our casks, the ones we are familiar with at least, have a fair degree of confidence that they do meet it. The fact that the flame temperature exceeds 2,000° F does not mean that the shell temperature will approach that temperature. The shell temperature may be only, say, 1000° F at the end of one hour, and still have considerable strength. There is a great deal of uncertainty in these calculations, however, and we do need further data.

(UK comment) - We rather agree that the nature of the fire is likely to occur in transportation may not be represented by the standard building fire. For this reason as you see in the paper that is going to be given to you later showing the tests,we propose an 800° Centigrade fire. That is the mean effective temperature. We are not saying that this is a flame temperature. We are saying that the test should be done in a furnace, and it should be for a half an hour. The reason we go to the furnace is that we want reproduceability. We do think there is a need for a test and it must be a standard test. We cannot represent every accident. We must select one accident or perhaps a set of conditions, and if the container or flask leaks under test conditions, it will be regarded as reasonable evidence that the container is not capable of withstanding the conditions likely to be met in practice.

SESSION III - TESTING PROGRAMS RELATED TO CONTAINERS FOR TRANSPORTATION OF RADIOACTIVE MATERIALS

AFTERNOON - 4 DECEMBER 1962

Professor J. T. Thompson, Johns Hopkins University, Session Chairman.

Session Chairman: All of the papers this afternoon have something to do with impact testing. I might say just for a moment that this is something that has concerned me for many years but I have been dealing with it in an entirely different field. I can't say related field because it has to do with motor vehicle transportation but we have had to theorize for 40 years about the behavior of pavement in relation to motor vehicles and we have not by a long shot answered most of these questions.

Although not directly attributable to an impact phenomenon in the sense I have spoken of, we have killed many people on the highway and millions of people have been injured who wish they were dead. But don't get discouraged. We are in a new industry. We have been at it only a little while and we have a lot to learn. I dare say we won't learn it all this afternoon.

The first paper will be given by Mr. J. M. Hoffman of the Engineering Department of DuPont.

TEST OF FISSILE MATERIAL SHIPPING CONTAINERS

by James M. Hoffmann

E. I. du Pont de Nemours & Company
Engineering Department
Wilmington, Delaware

ABSTRACT

An investigation was made of the shipping container "bird cage" used for plutonium button shipments to assess what may happen to it in a railroad accident. It was found that in a rapid deceleration from 30 miles per hour the cage would suffer severe permanent distortion, but would remain intact.

INTRODUCTION

In July, 1961, at the request of the Atomic Energy Commission the Du Pont Company evaluated the structural steel "bird cage" used to ship plutonium buttons off-site from the Savannah River Plant with respect to its ability to withstand impact forces. These bird cages are used in railroad shipments which may be subject to an accident with resulting impact or rapid acceleration forces. The question was, "What might happen to the bird cage in a credible railroad accident?"

While there have been many railroad accidents, little is known about the forces and accelerations produced in such an incident.

R. G. Stanford, in his Johns Hopkins thesis (NY09374 May 1961) states that data necessary to develop the required information for an analysis of this type have not been collected.

Since railroad accidents run the gamut from minor jars, almost imperceptible, to complete and total demolition, some basis for the study had to be selected. It was assumed that the railroad car containing the bird cages strikes an almost unyielding object at 30 miles per hour. It was also assumed that this car would be the only car involved, that it would not be subject to crushing from other cars in the train crashing into it.

CURRENT SHIPPING PRACTICES

Plutonium buttons for shipment off-site are stored in bird cages that are designed to provide the spatial arrangement necessary to prevent a nuclear incident which results when a critical mass of plutonium is created. This bird cage is shown on Slide No. 1. It is a structural steel cube whose sides measure 20". In the center is a covered container in which a canned plutonium button is placed.

The bird cages are shipped from the Savannah River Plant in a modified Atlantic Coast Line baggage car, normally hauled directly behind the engine of a passenger train. One half of the car contains living quarters for the escorts and the other half is fitted out for holding several types of shipping containers. The facility for holding the bird cage consists of a structural steel framework as shown in Slide No. 2. The bird cages are held in the individual compartments by pieces of strap iron fitted in clips which can be seen in the slide. The structural framework is welded to the 1/4" checker plate floor and is braced to the overhead.

STRUCTURAL ANALYSIS

In analyzing what might happen to the bird cage when the railroad car came to an abrupt stop from 30 miles per hour, it was assumed that the bird cage itself went through this rapid deceleration. Actually, this would not be the case in a wreck since various components of the car and bird cage compartment would absorb some portion of the forces involved before the bird cage was affected. In addition, no consideration was given to the possible missile effect of other items in the car which may strike the bird cage and upset the safe array.

Since the bird cage support or racks could be expected to distort in a wreck, it was assumed that the bird cages themselves would be supported at their corners only. Under these conditions, the vertical members of the bird cage could absorb energy through deflection. If they were not permitted to deflect, the central container and the cross angles would be subjected to much higher impact forces.

The analysis of even a simple structure subjected to dynamic loading becomes very difficult and time-consuming. To design and analyze a structure for conventional static loads, it is assumed that the applied load and internal forces are closely balanced at all times. Thus, the acceleration of the structure and its members is practically zero and is negligible. Stresses and strains of the loaded member can then be computed on the basis of static equilibrium by equating the resisting forces to the design loads.

In the case of rapidly or instantaneously applied loads, the internal forces resisting deflection will not be immediately and continuously equal to the applied loads and the resultant

acceleration of the member or its parts will be significant. Furthermore, peak applied loads may exceed the static strength of a structure without causing failure provided the loads are of short enough duration.

The maximum stresses and, more important the maximum displacement, produced by dynamic loads are a function of:

1. intensity of applied load
2. rate of application of load
3. duration of load
4. particular variation with time of applied load
5. particular variation with time of the resistance provided by the structure

These stresses and displacements are generally far different from those which would result from a static load of equal magnitude.

In order to determine an order-of-magnitude value for the allowable impact velocity, it was decided to resort to the admittedly very approximate method of equating the energy-absorbing potential of the bird cage as determined by static limit-load analysis to the kinetic energy at impact. The allowable impact velocity thus determined was very low, on the order of 2.8 miles per hour.

In order to determine the actual strains existing in the structural members of the bird cage, two tests were conducted using SR-4 strain gages. These gages were attached to the bird cage as shown on Slide No. 3.

In the first test, the bird cage was dropped from varying heights up to a maximum of 24" which is equivalent to an impact velocity of approximately 8 miles per hour, a speed that may be experienced

during "humping" operations on a railroad. Slide No. 4 shows the results of this test, indicating that general yielding occurs at all locations when the impact velocity approaches 8 miles per hour.

The bird cage was then tested on an inclined-plane railroad car simulator at the Du Pont Engineering Test Center. Deceleration forces, measured by a fifty-G accelerometer clamped to the cylinder, and dynamic strains in the lower edge of a diagonal cannister support, adjacent to the cannister, were recorded on a visicorder. Slide No. 5 shows the location of the strain gage. Slide No. 6 shows the resulting dynamic and permanent strains. The strain gage was damaged when the impact velocity reached 8.50 miles per hour.

Slide No. 7 shows the recorded decelerations. The accelerometer had to be removed to avoid damaging it when the deceleration exceeded 50 G's, which occurred at an impact velocity of slightly more than 5 miles per hour. Projection of the deceleration curve indicates that at an impact velocity of 8 miles per hour, which caused significant dynamic and permanent strains, the container is subjected to deceleration forces in excess of 100 G's.

It should be noted that the deceleration force curve indicates the resistance of the structure to the forces exerted; i.e., if there were no resistance, there would be no forces. When the applied forces become equal to the maximum resistance that the structure is capable of offering, no additional force can exist. It is also true that if the structure is modified, its resistance is changed, which in turn changes the deceleration force curve.

Following these tests, the bird cage was subjected to a drop test to simulate impact at 30 miles per hour against an almost unyielding surface. Here, the cage was lifted by a crane and dropped on a massive concrete foundation. In order to simulate the deflection of the support frame in the railroad car, thereby providing point support at the corners of the bird cage, rods one inch in diameter and one-half inch long were taped to the four corners that would hit the concrete. The trip mechanism held the cage in a position that allowed it to land vertically, simulating forward motion of the cage in the railroad car. The following movie film shows the two drop tests that were conducted. Note how similar the damage is in both bird cages.

(The motion pictures show the actual drop tests of two bird cages in "slow motion". Exhibit "A" of this paper shows the two bird cages after dropping, illustrating the distortion of the members. Large cracks were developed in the corner welds where stress concentration is high.)

CONCLUSIONS

After analyzing the test data, the following conclusions were made:

1. When subjected to the loading specified for the analysis, the bird cage will suffer severe permanent distortion, but will remain intact, providing such distortions are not prevented by the supporting rack or structure.

2. The present rack and cage provide little protection from:
   a. hurtling objects within the car,

b. projectiles from outside the car, such as a track rail penetrating from below,

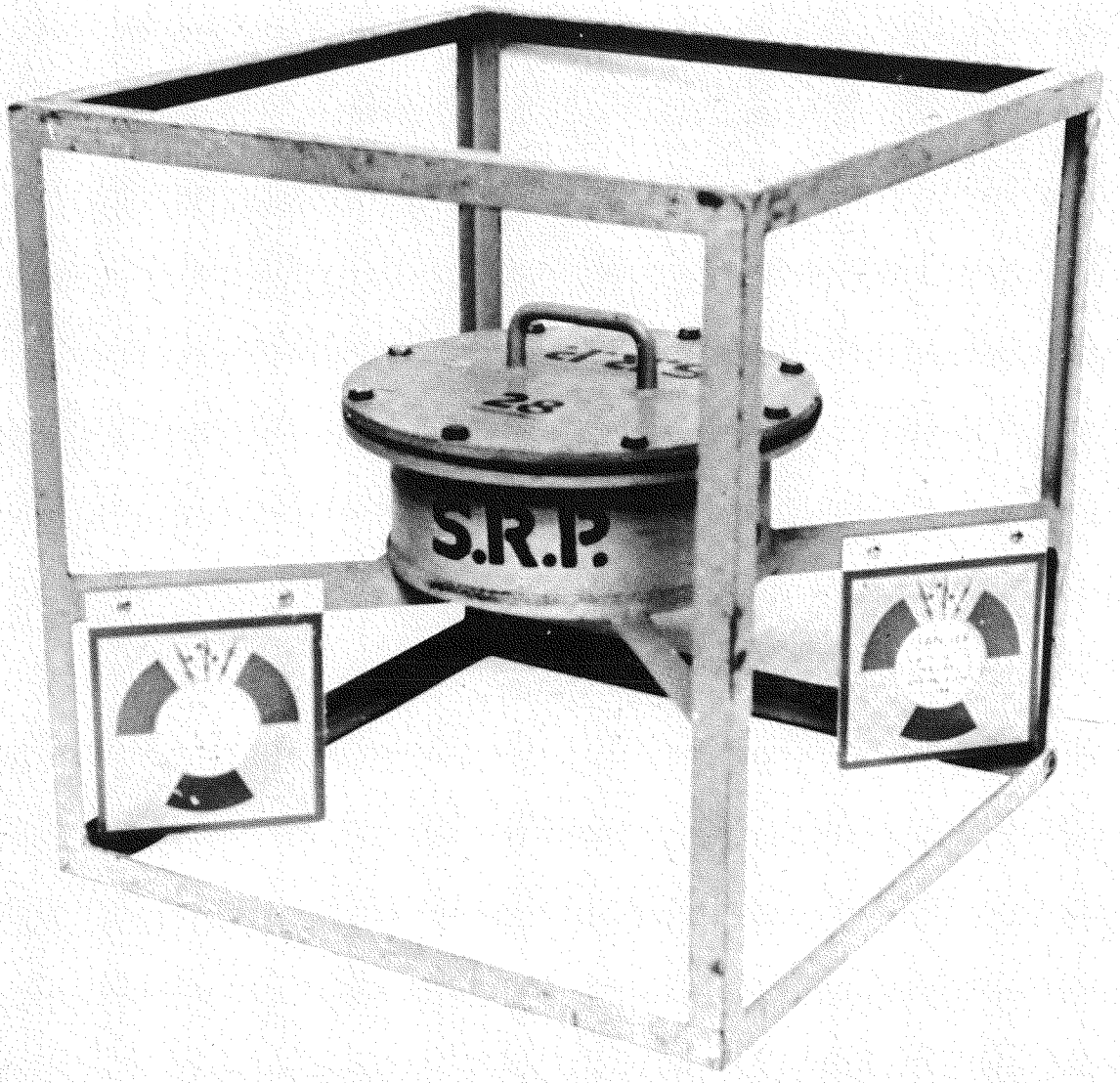
c. crushing of the car and contents by other cars piling into it, and

d. fire.

Consideration should be given to these in any program involving modifications to the present shipping practices.

This information contained in this article was developed during the course of work under Contract AT(07-2)-1 with the U. S. Atomic Energy Commission.

SLIDE NO. 1



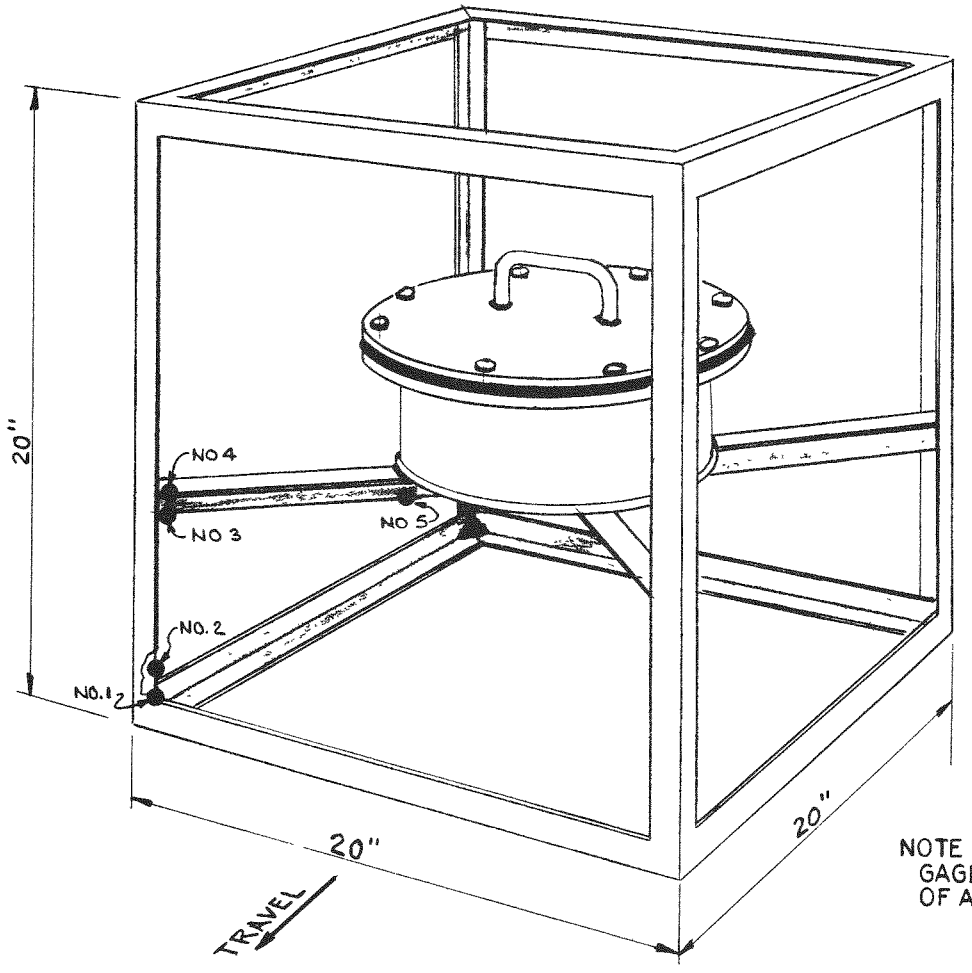
PLUTONIUM BUTTON SHIPPING BIRDCAGE

SLIDE NO. 2



RAILROAD CAR FRAMEWORK FOR BIRDCAGES

SLIDE NO. 3

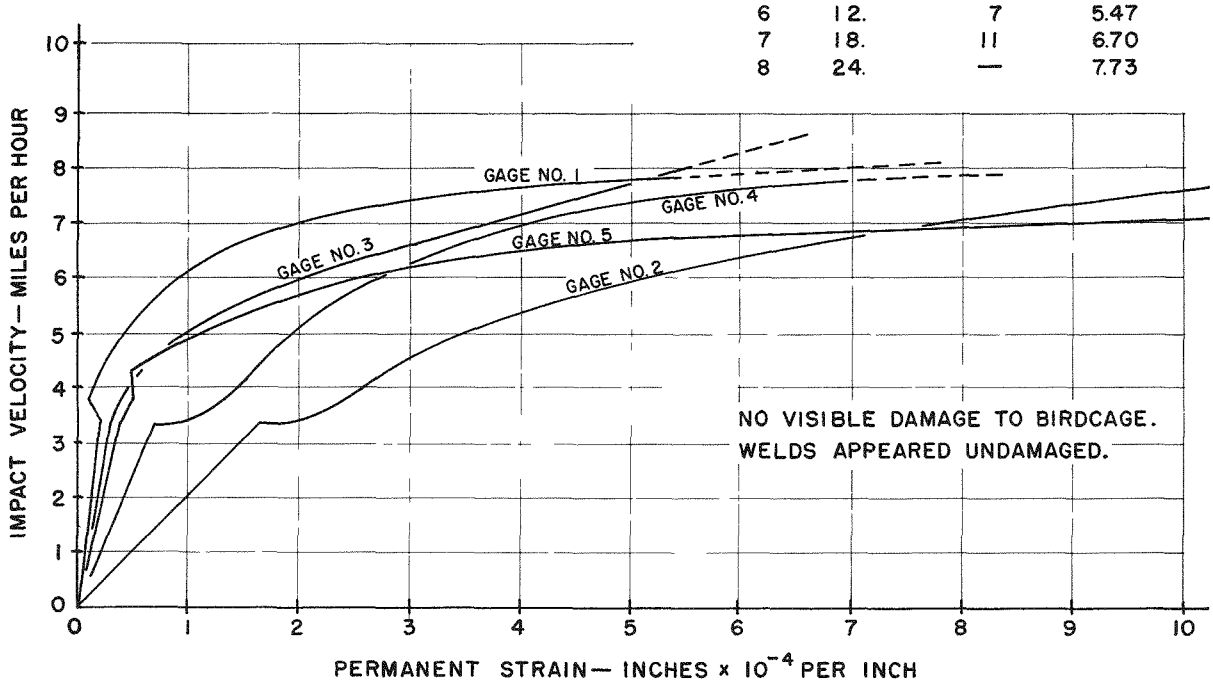


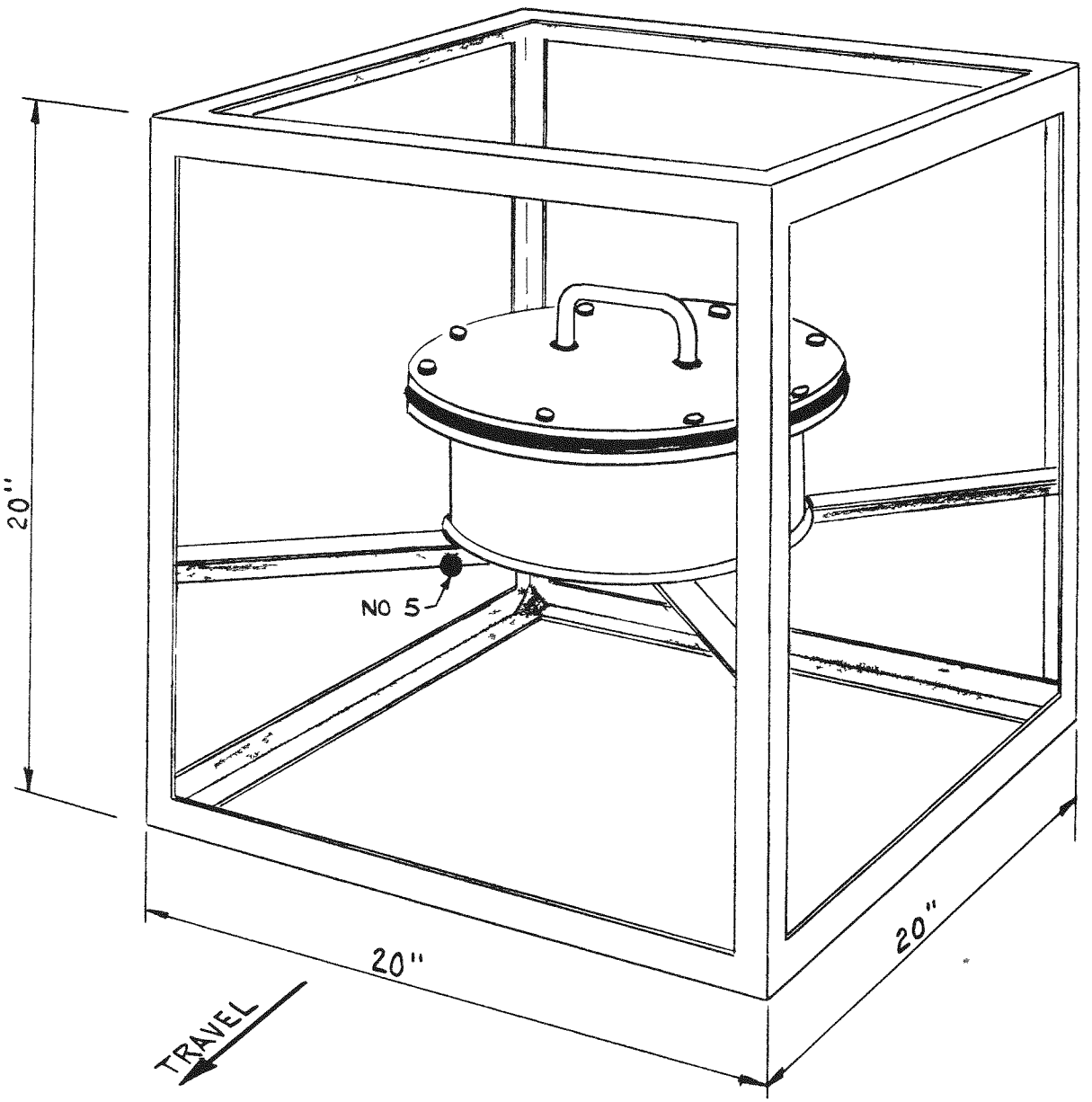
NOTE
GAGES PLACED ON EDGES
OF ANGLE LEGS

STRAIN GAGE LOCATIONS
FOR DROP TEST

DROP TEST OF BIRDCAGE
AT LOUVIERS BUILDING
AUGUST 2, 1961

RUN NO.	DROP HEIGHT INCHES	APPROX REBOUND INCHES	VELOCITY M.P.H.
1	5.5	—	3.70
2	4.5	—	3.35
3	5.6	—	3.74
4	7.3	3	4.25
5	9.5	4	4.85
6	12.	7	5.47
7	18.	11	6.70
8	24.	—	7.73

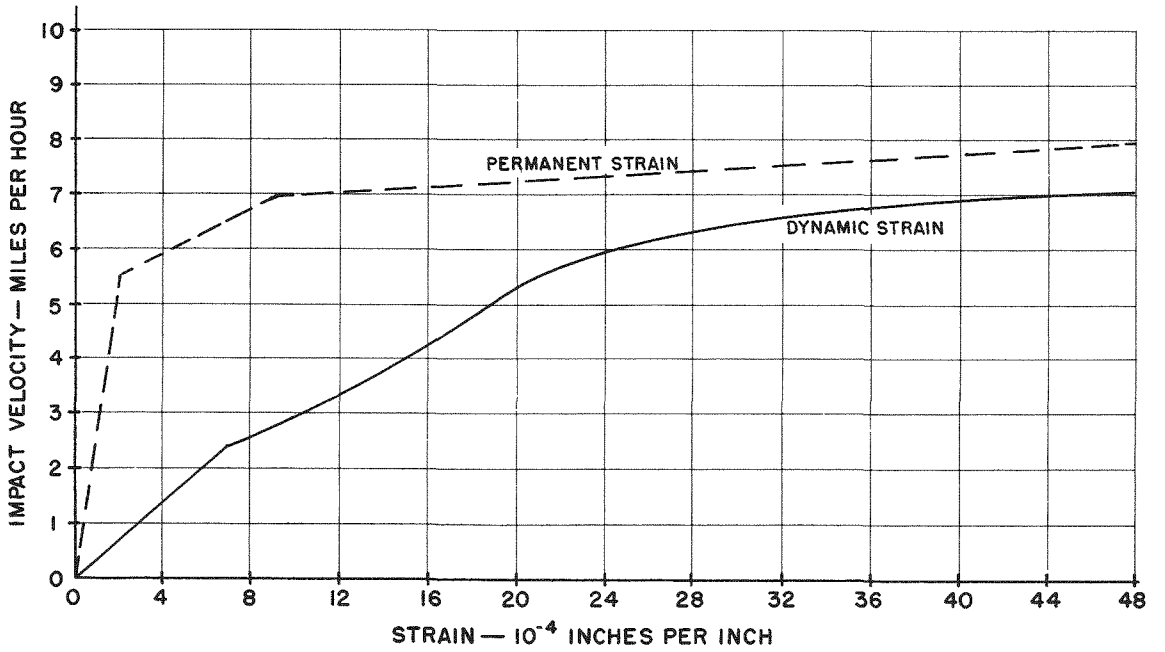




STRAIN GAGE LOCATION
FOR INCLINED PLANE IMPACT TEST

DYNAMIC & PERMANENT STRAIN

INCLINED PLANE IMPACT TEST
ENGINEERING TEST CENTER
AUGUST 4, 1961



SLIDE NO. 7

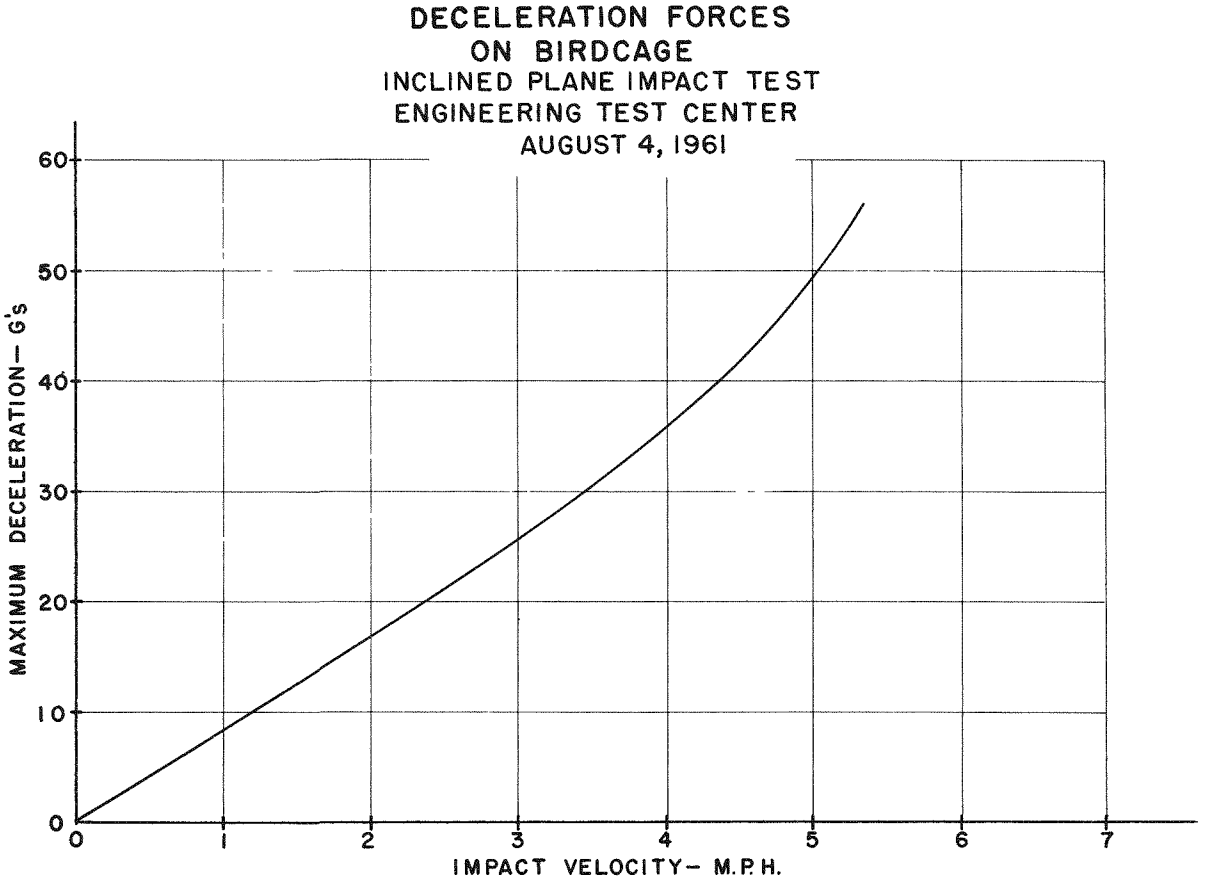
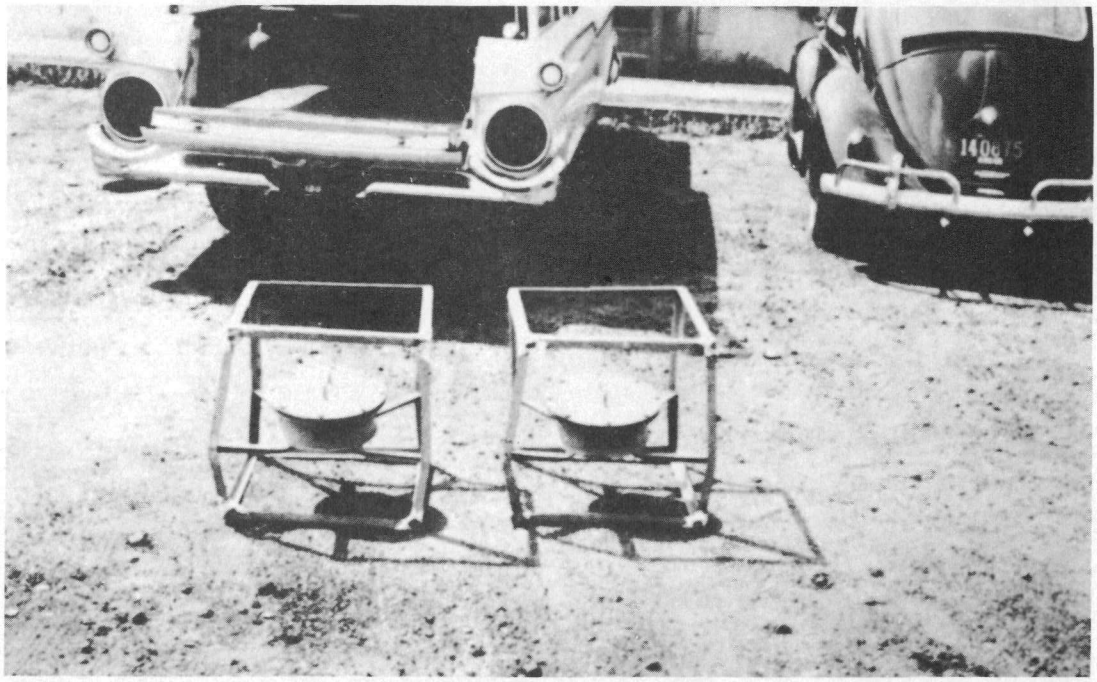
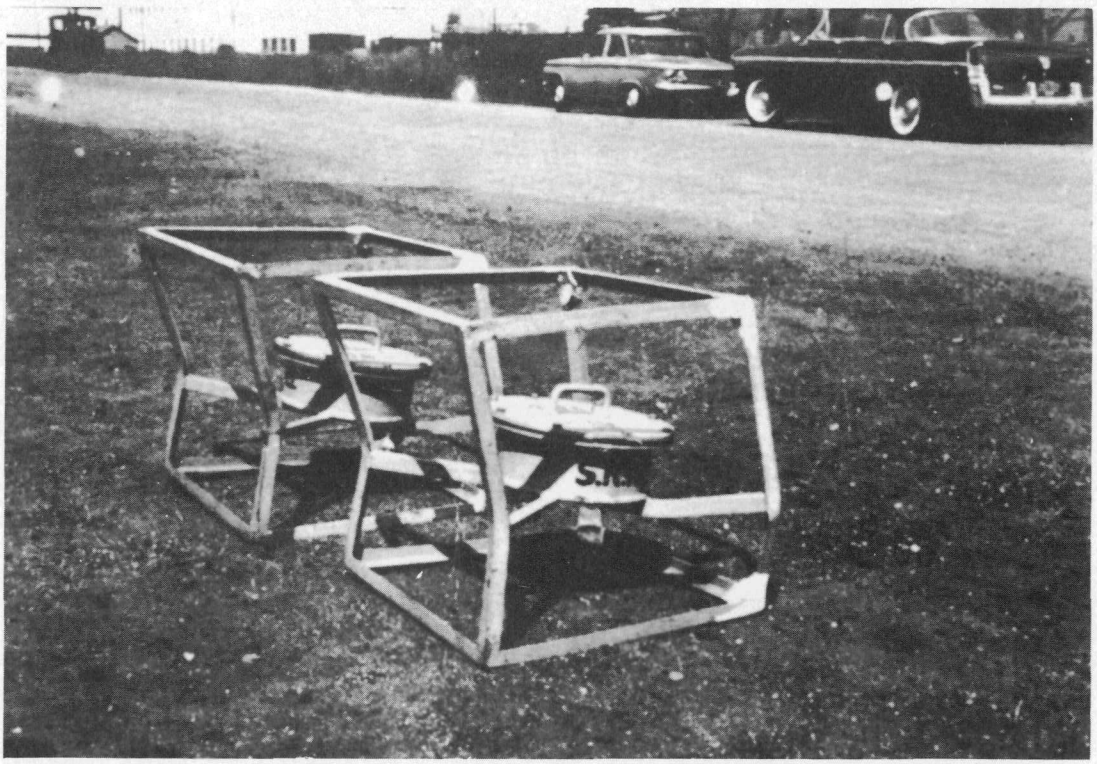

DECELERATION FORCES
ON BIRDCAGE
INCLINED PLANE IMPACT TEST
ENGINEERING TEST CENTER
AUGUST 4, 1961
MAXIMUM DECELERATION— G's
60
50
40
30
20
10
0
0
1
2
3
4
5
6
7
IMPACT VELOCITY— M.P.H.

EXHIBIT A





BIRD CAGES AFTER DROPPING 30' (30 MILES PER HOUR)
SCENES TAKEN FROM FILM OF DROP TEST

Remarks by Mr. Hoffman: I would like to add that both Hanford and Savannah River use this "bird cage". It was originally designed for Hanford. Earlier it was taken up in an airplane and dropped and it survived. However, both sites are currently looking into means of providing additional "over-the-road" safety for this method of shipping plutonium buttons.

Currently, we are concentrating on providing additional protection from fire and not so much from other cars crashing into it and things of that nature.

Session Chairman: The next paper is by Mr. J. D. McLendon of the Union Carbide Nuclear Company.

TESTS OF A PROPOSED URANIUM CONTAINER

J. D. McLendon

UNION CARBIDE NUCLEAR COMPANY
Division of Union Carbide Corporation

Y-12 PLANT

ABSTRACT

A simple, relatively cheap shipping container, available from many potential suppliers, has been designed and tested for impact and fire resistance. Although tests have been limited, results meet, or exceed, specifications of proposed standards. In view of favorable fire and impact resistance, and considering mechanical and geometric design, it is concluded that nuclear safety of enriched uranium shipments in these containers would be at least as good as that experienced with Y-12 birdcages.

The container currently meets Class II, IAEA requirements. With some modifications it is conceivable that Class I specifications can be met.

INTRODUCTION

The earliest needs for transportation of enriched uranium were met admirably by use of a gasketed, metal container suspended in the center of an angle-iron frame. It was natural that such a device should be called a "birdcage". The adequacy of this type of shipping container is attested by the fact that birdcages have remained in service for all of these nearly twenty years of atomic energy work.

During these years, however, with growth of the enriched uranium business from defense to practical commercialization, shipping requirements have accelerated many fold. Concern for costs has resulted in the use of a wide assortment of containers and utilization of every conceivable mode of transportation. With due respect to American ingenuity and freedom of choice, it has become apparent that uniform shipping container and transportation specifications are necessary.

In recognition of the two factors of: (1) the need for a cheap, but adequate container, of simple, standard design, and (2) impending regulations to control shipments, some thought has been given to the problem at Y-12. The following presentation will discuss conceptual ideas for such a container for enriched uranium and tests for conformance to impact and fire resistance criteria.

DESIGN FEATURES AND CONSTRUCTION DATA

The basic design concepts were set as follows:

1. Provide nuclear safety at least as good as that experienced with Y-12 birdcages, with specific reference to mechanical integrity, permissible loading, and transportation limits.

2. Meet applicable impact, puncture, and fire resistance specifications.

3. Use materials commonly available from a wide variety, and large number, of suppliers.

4. Permit ease of handling, sealing, and contamination control.

5. Keep costs as low as possible, within the specifications framework.

With these design concepts in mind, efforts were made first to take advantage of packages available from commercial suppliers. A fiberglas and a steel container, both designed to military drop specifications, (1) were procured. The fiberglas container was rejected because of inadequate fire resistance and cost. The steel container was fitted with foamglas, a common insulating material available from building suppliers, together with a formed plastic liner. Fire tests were undertaken at Y-12 by an MIT study group as part of an on-site cooperative training program. Results of these tests and further investigation of available materials produced the container design shown schematically in Figure 1. Details of foamglas loading in this container are shown in Figure 2.

Salient features of the container are tabulated in Table I. It is of particular interest to note that many drum manufacturers can supply the metal shell with relative ease, and installation of foamglas can be done with equal dispatch by any one of many insulation contractors. Thus, the design criterion of universal availability of materials and labor seems fulfilled. In addition, the use of the common drum would permit standard handling methods and fixtures. The smooth enameled surface could be readily cleaned or spray painted for contamination control. Because of the closed bubble makeup of the foamglas, the drum has sufficient buoyancy to float readily when loaded to its anticipated maximum.

FIRE TESTS

Proposed revisions of Interstate Commerce Commission regulations pertaining to the rail transport of radioactive materials(3) and pending changes in AEC licensing regulations(4) require that containers must be adequate to prevent the loss or dispersal of radioactive materials as a result of the action of the standard one-hour fire as published by the National Fire Protection Association (NFPA No. 251).

The NFPA test is controlled by a time-temperature relationship. The standard curve is determined by the following points:

1000° F (538° C) - After 5 minutes
1300° F (704° C) - After 10 minutes
1500° F (843° C) - After 30 minutes
1700° F (927° C) - After 1 hour

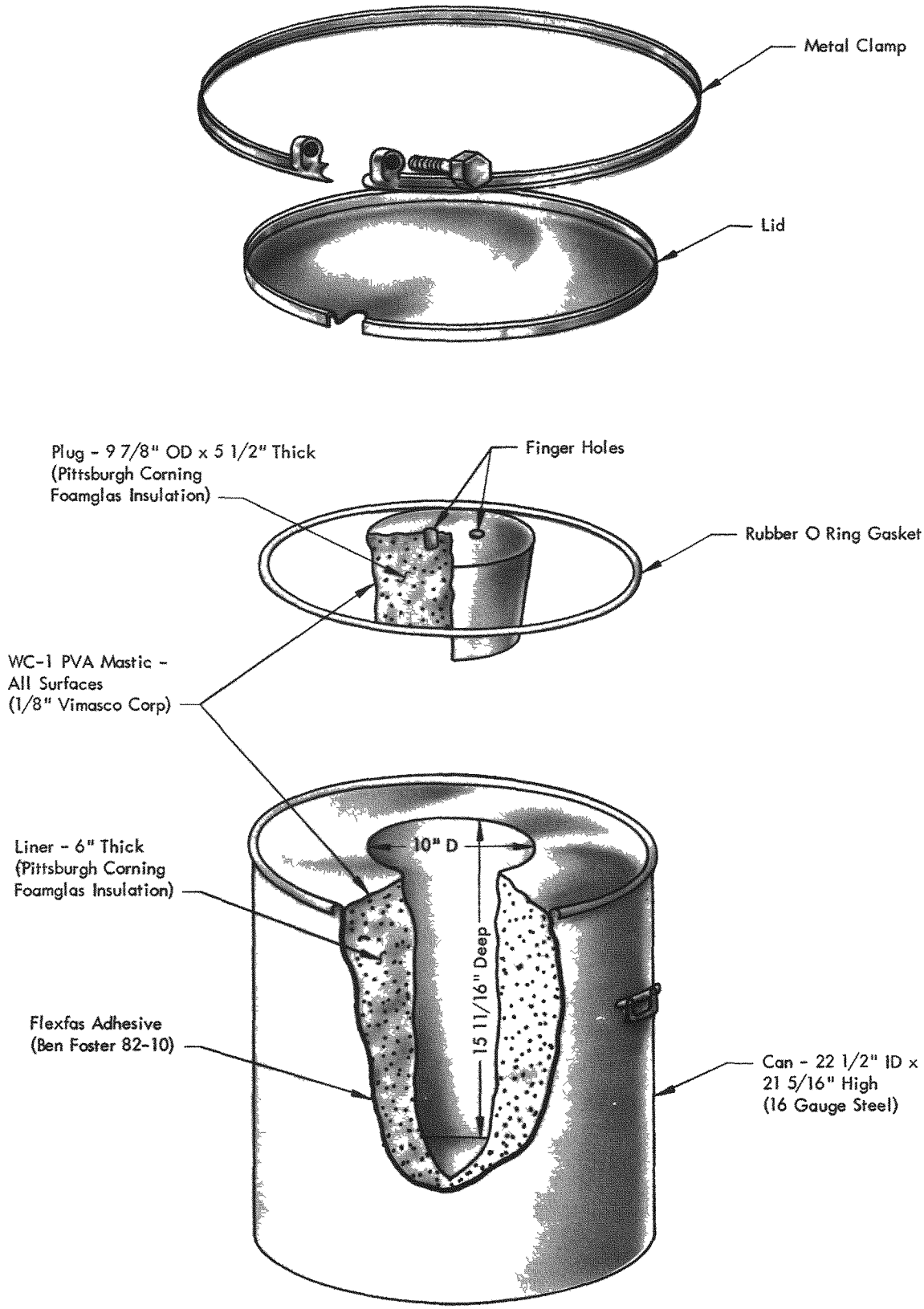
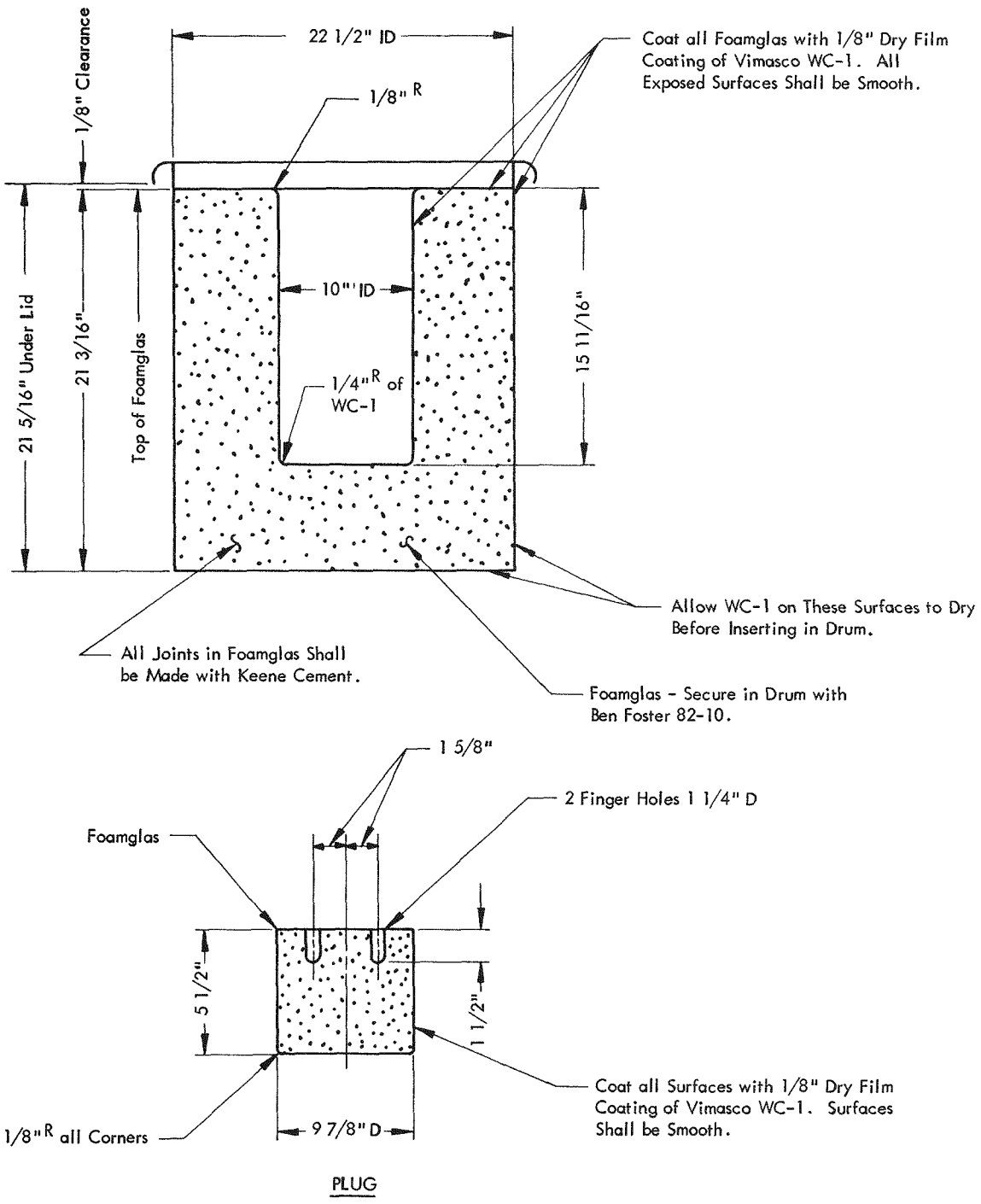


Figure 1 Y-12 FOAMGLAS SHIPPING CONTAINER



Note: Reinforce all exposed surfaces with glass cloth.

Figure 2. Y-12 SHIPPING CONTAINER INSULATION.

Table 1

Y-12 FOAMGLAS SHIPPING DRUM

Overall Weight	95 lbs
Overall Cost	$51.28
Outer Shell	Standard 55-gallon drum, manufactured to special inside height of 22 inches; diameter - 22 1/2", 16-gauge carbon steel, black enamel finish; two drop side-leaf handles provided.
Closure	Standard drum lid with bolted ring clamp.
Water Tightness	Gasketed lid using 0.25" diameter hollow Neoprene gasket.
Weight of Shell	48 lbs
Manufacturer	Any drum manufacturer; fabrication machinery easily changed since diameter is standard.
Cost	$11.28 (Inland Steel Container Co, Cleveland, Ohio)
Inner Cavity	
Size	10" diameter by 10" high.
Lining Material	Polyvinylacetate (PVA), about 1/16" thick.
Decontamination Ability	PVA is washable, waterproof, acid and alkali resistant.
Lining Application	Can be hand applied as putty-like material; sets in 24 hours.
Manufacturer	Several; present supply, Type WC-1, Vimasco Corp, Nitro, West Virginia.
Cost	$4/gal; covers 12 sq ft to 1/8" thick, setting to about half this thickness.
Foamglas	
Material	Borosilicate glass.
Cellular Structure	Closed bubble foam; voids filled with H_2S.
Total Weight	47 lbs (includes PVA lining).
Compressive Strength	100 psi
Maximum Permissible Temperature	800° F is recommended maximum for normal use.
Moisture Absorption	0.2% by volume by ASTM C-240-50T.
Fabrication of Container	Can be done by any piping insulation contractor.
How Obtained and Worked	Blocks measuring 4" by 18" by 24", can be cut as with wood.
Uniformity of Material	Presumed good; batches are made up from new materials, formula not varied.
Manufacturer	Pittsburg Corning Corp, Dept S-8, One Gateway Center, Pittsburgh, Pennsylvania.
Cost	$40 for labor and materials for drum; (North Bros, Knoxville, Tennessee).

Two separate tests have been performed on Y-12 drums by use of an electric resistance furnace capable of temperatures up to 2300° F. These tests were instrumented by use of beaded or stainless steel encased chromel-alumel thermocouples recording through a Leeds and Northrup, Speedomax, eight-point recorder. Although the prime objective was to evaluate fire resistance of the container, it was of interest to determine ability to conform to NFPA test requirements. These two tests will be discussed in detail.

Fire Test 1

A sealed drum with no loading in the central cavity was inserted into the oven (29" H by 33" W by 78" L) after it had been preheated to 1000° F. Figure 3 is a top view of the open drum in which the location of the thermocouples can be seen. Double thermocouples were used at each location to ensure positive results.

The specific locations were:

1. Outside surface of drum (skin temperature).

2. Inside foamglas, 11" deep centered between cavity wall and outside surface.

3. Inside central cavity.

Figure 4 charts the changes in temperature at the three points.

Soon after insertion into the heated furnace, smoke began to be evolved. In addition, the periodic ignition of combustible gases caused noticeable temperature fluctuations in both the furnace and at the container surface. The furnace thermocouple recorded temperatures ranging from 750 to 1000° F during a period of about 25 minutes. At this time it was necessary to open the furnace vent in order to control the smoke. Needless to say, this further affected the time-temperature relationship. After a period of a little over 1 1/2 hours, the furnace temperature reached 1700° F at which time the test was terminated. Container condition after removal can be seen in Figures 5 and 6. Conclusions from this test included the following:

1. The skin temperature of the container fell far short of that desired when compared with the NFPA curve.

2. The basic geometric integrity of the container was retained although the gasket was destroyed and the plastic liner had burned and cracked.

3. Slight evidence of melting of foamglas on the top surfaces was observed.

In general, this first test was reasonably successful; however, a retest was considered necessary to overcome the shortcomings encountered.

Fire Test 2

In order to attempt to meet the standard time-temperature requirements, and for other improvements, the second test was performed in the same furnace with a few minor changes:

1. The furnace was preheated to 1700° F before insertion of the container.

2. The furnace vent remained open during the entire run.

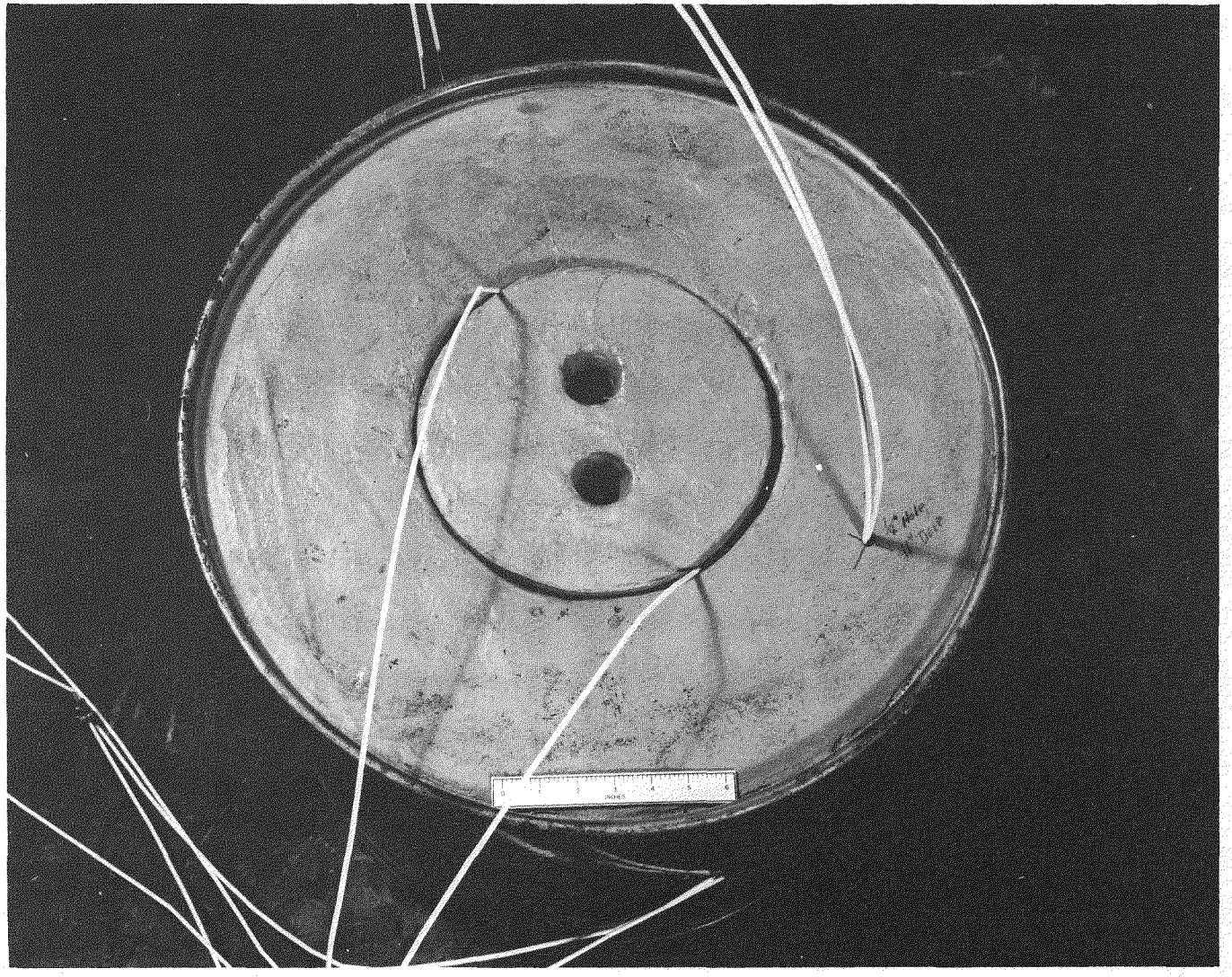


Figure 3. TOP VIEW OF OPEN DRUM. (Note Location of Thermocouples)

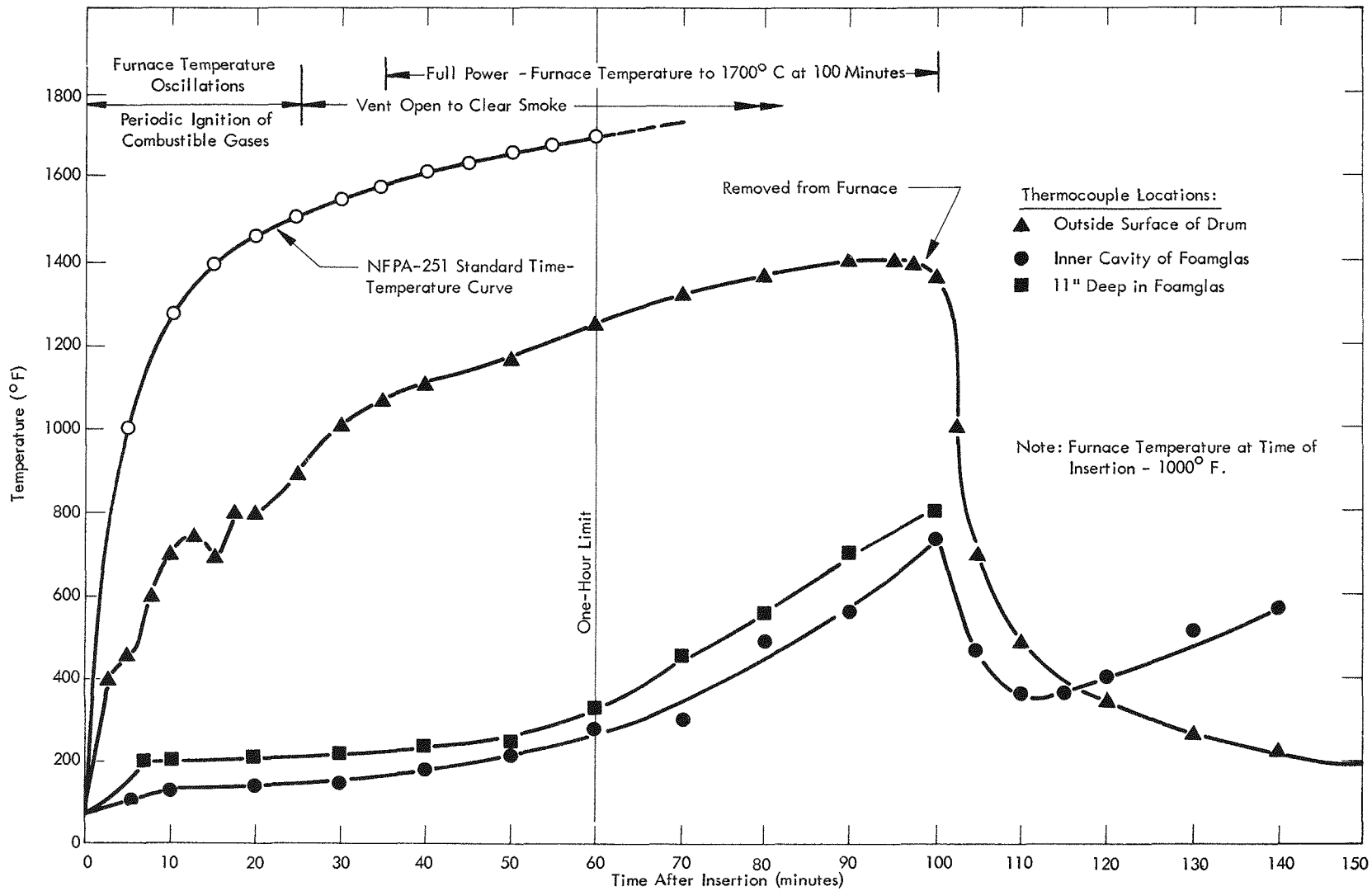


Figure 4. CHANGES IN TEMPERATURE AT THE THREE POINTS. (Fire Test 1)



Figure 5 CONTAINER CONDITION AFTER FIRE TEST 1 (Side View)



Figure 6 CONTAINER CONDITION AFTER FIRE TEST 1 (Top View)

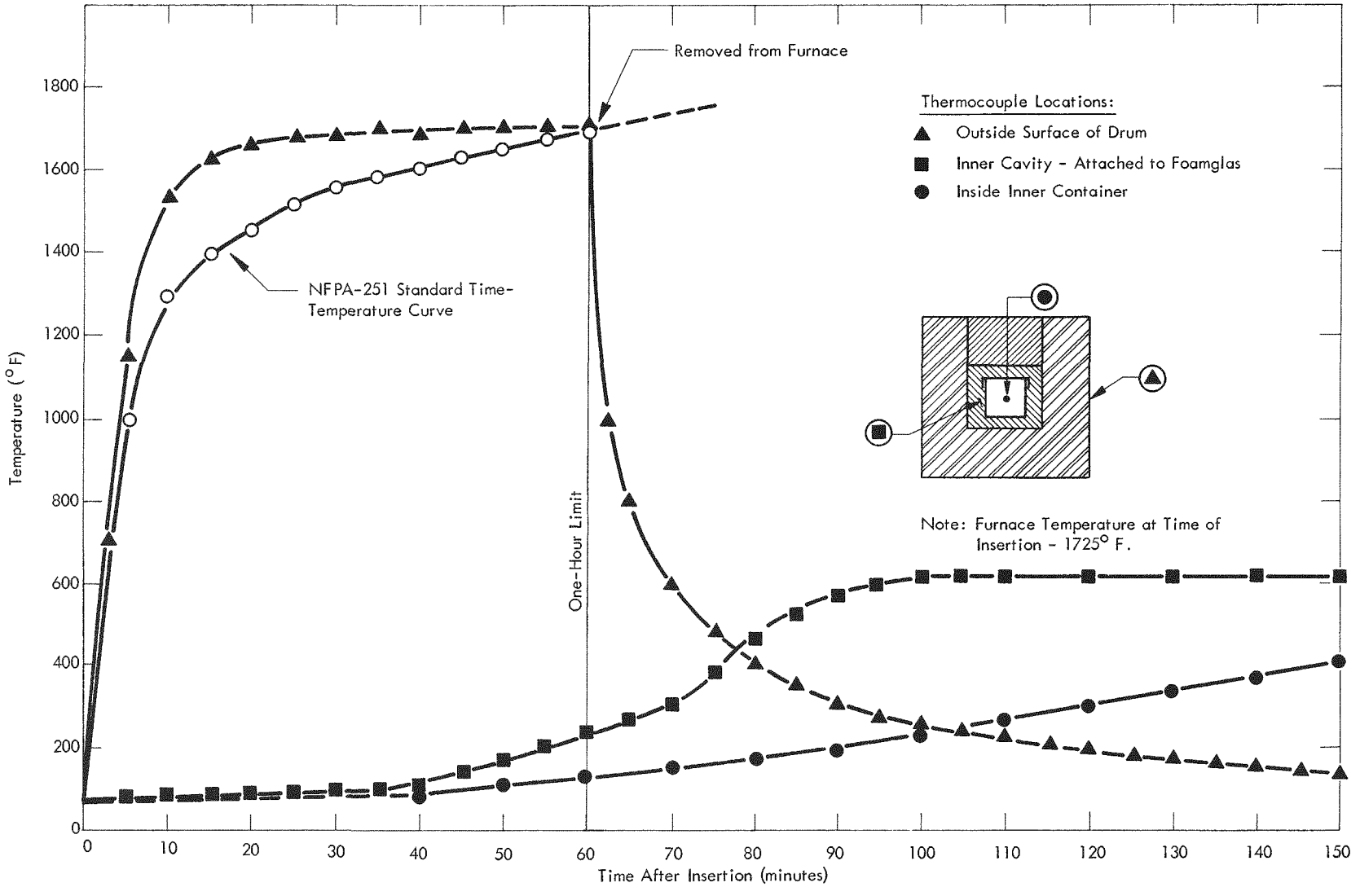


Figure 7. CHANGES IN TEMPERATURE AT THE THREE POINTS. (Fire Test 2)



Figure 8. CONTAINER BEFORE FIRE TEST 2.

3. The PVA coating in the drum included a heavier layer of open mesh glass cloth.

4. The central cavity was filled in a typical manner, as it might be during shipment. A stainless steel hospital can was packed with miscellaneous articles. Included were: two plastic bottles, a piece of wood, a stainless steel bolt and screw, and a piece of mild steel, all of which were packed in paper. The loose fitting cover was taped to the can, which was centered in the drum cavity by filling the remaining void with vermiculite.

5. The thermocouples, previously positioned in the foamglas, were moved inside the can to record the temperature in the load zone itself.

After the furnace had reached 1725° F and had been allowed to "soak" thoroughly, the door was opened and the can inserted. Immediately, the enameled surface burst into flame. The furnace temperature dropped momentarily to ~1600° F but recovered in about five minutes. Inspection of Figure 7 shows that the skin temperature of the drum rose sharply for the first ten to fifteen minutes, then leveled off nicely at about 1700° F. The time-temperature curve exceeded the NFPA requirement at all times. Since the standard required a one-hour test, the unit was removed from the furnace at that time and was allowed to cool in the room atmosphere.

Observation of the temperatures inside the cavity and in the loaded can indicates that the load temperature remained below 150° F at one hour and the cavity wall was only 215° F. After removal from the furnace, however, the internal temperature continued to rise. The cavity wall maximized at a little over 600° F in an additional hour, whereas, the can temperature continued to rise for an additional 1 1/2 hours. It appears that the can temperature would not have exceeded 450° F. It is suggested that in an actual case of fire, the inside temperature would be depressed below these values by normal fire fighting techniques. Figures 8 and 9 show before and after views of the container. The post-test view reveals cracking of the PVA coating and a small amount of melting of the foamglas surface; however, few other deleterious effects are noticeable. The foamglas plug and hospital can have been removed from the cavity in Figure 10. The following observations are apparent:

1. The PVA coatings inside the cavity and on the bottom of the plug have remained essentially intact; although charred.

2. Melting of a part of the top surface of the foamglas was limited to less than one inch.

3. Vermiculite in the inner cavity showed little change.

4. Contents of the metal can were not seriously damaged with the exception of the two plastic bottles which had melted. Even for these, however, fragments remained undestroyed.

A closer view of the contents of the can in Figure 11 shows most clearly that even the paper itself remained readable, particularly in the center layers. Wood and steel, although discolored, were undamaged.

Fire Test Conclusions

1. The insulating value of foamglas provides adequate protection against credible fire exposures. Excluding highly pyrophoric forms of uranium, little damage would be expected to the contained load.

2. Vermiculite exhibits excellent fire resistance characteristics.

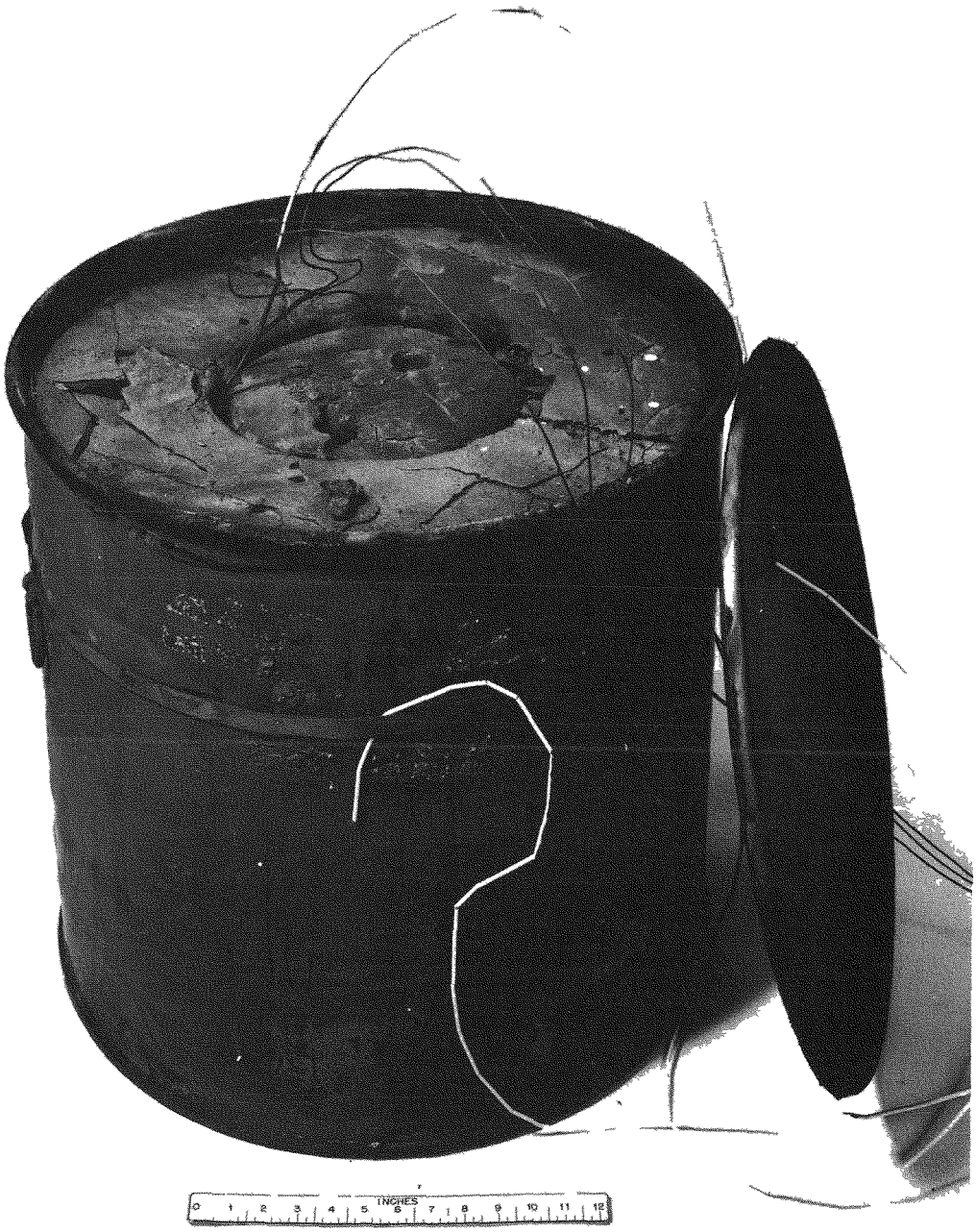


Figure 9. CONTAINER AFTER FIRE TEST 2.

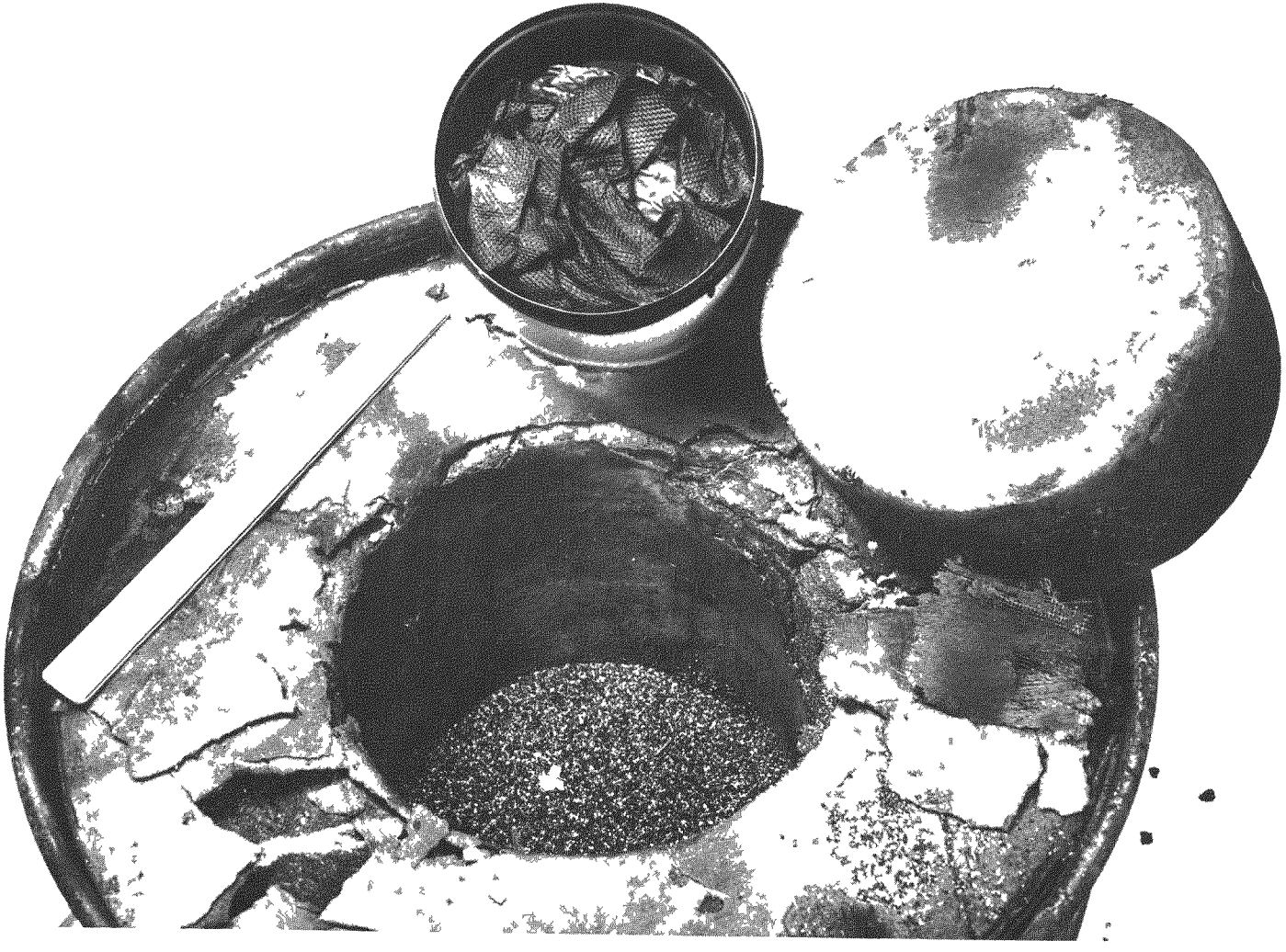


Figure 10 FOAMGLAS PLUG AND HOSPITAL CAN AFTER FIRE TEST 2

3. The basic physical integrity of the container has been demonstrated. No loss or dispersal of radioactive materials is expected as a consequence of fire.

4. Inner container designs must recognize the problems peculiar to the physical and chemical makeup of the load; however, this is a problem common to all containers. Tests, such as these, permit the establishment of realistic assumptions for design specifications. For example, it appears feasible to establish pressure criteria for containers loaded with liquids on the basis of maximum attainable temperatures.

5. Even though the container would remain afloat when placed in water, inleakage must be assumed in criticality evaluations due to loss of the gasket.

6. A simple testing technique has been demonstrated which appears to satisfy the standard one-hour NFPA time-temperature requirements.

DROP TEST

Various drop tests have been suggested; however, the most recent drafts of standards[3, 4] require a "free fall on any side, including top and bottom, from a height of 30 feet on an unyielding horizontal flat surface". The two tests to be described were performed before this height was firmly suggested and were done from the maximum then considered reasonable, 40 feet.

These drop tests were done in the simplest manner possible. No impact, strain, or compressivity gauges were used. The test consisted simply of a 42-foot free fall from the top of a building in Y-12 to the asphalt-paved road below. The damage was visually inspected and recorded by polaroid photographs.

The first drop was done with a drum loaded with three depleted uranium metal buttons which totaled 20 kilograms. In this test, the metal was placed in plastic bags and was packed in the drum cavity using corrugated packing paper. The drum was dropped twice from 42 feet, each time falling approximately on the same side. The side was pushed in about one inch, thus reducing the insulation thickness about 16% at the worst point. The buttons sliced through the foamglas liner and lodged against the metal shell. Otherwise, the drum remained intact.

Because of movement of the load, a second test was made. In this case, however, the buttons were packed inside a stainless steel hospital can which was then placed into the drum cavity. Paper was used inside and around the can. Again two drops were made, one from 22 feet and a second from 42 feet onto asphalt pavement. Efforts were successfully made to drop the container on its ring clamp as a test of closure integrity. Figure 12 shows the resulting damage from the two falls; the forward indentation being the result of the 22-foot fall. Figures 13 through 17 show various phases of the damage done.

Drop Test Conclusions

The following conclusions are made on the basis of these tests:

1. Enriched uranium, and possible higher specific alpha emitters, properly packaged in inner containers, would be adequately contained under accidents simulated by the test conditions.

2. The inner container must be large enough to distribute the force over an area sufficient to avoid penetration to the outer wall. Filling the internal void with vermiculite would provide practical immobility.

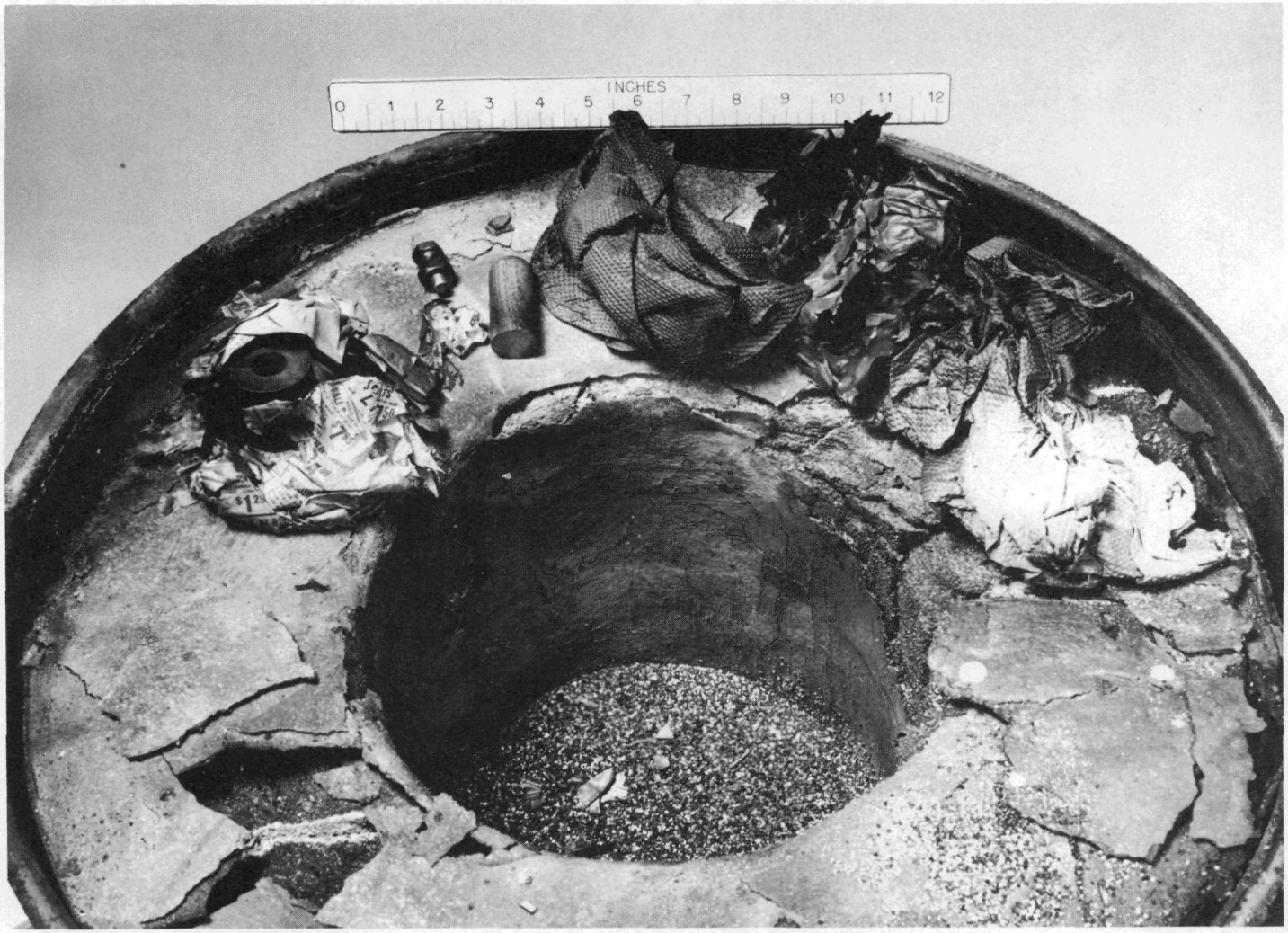


Figure 11. CONTENTS OF THE HOSPITAL CAN AFTER FIRE TEST 2.



Figure 12. CONDITION OF CONTAINER AFTER TWO DROPS.

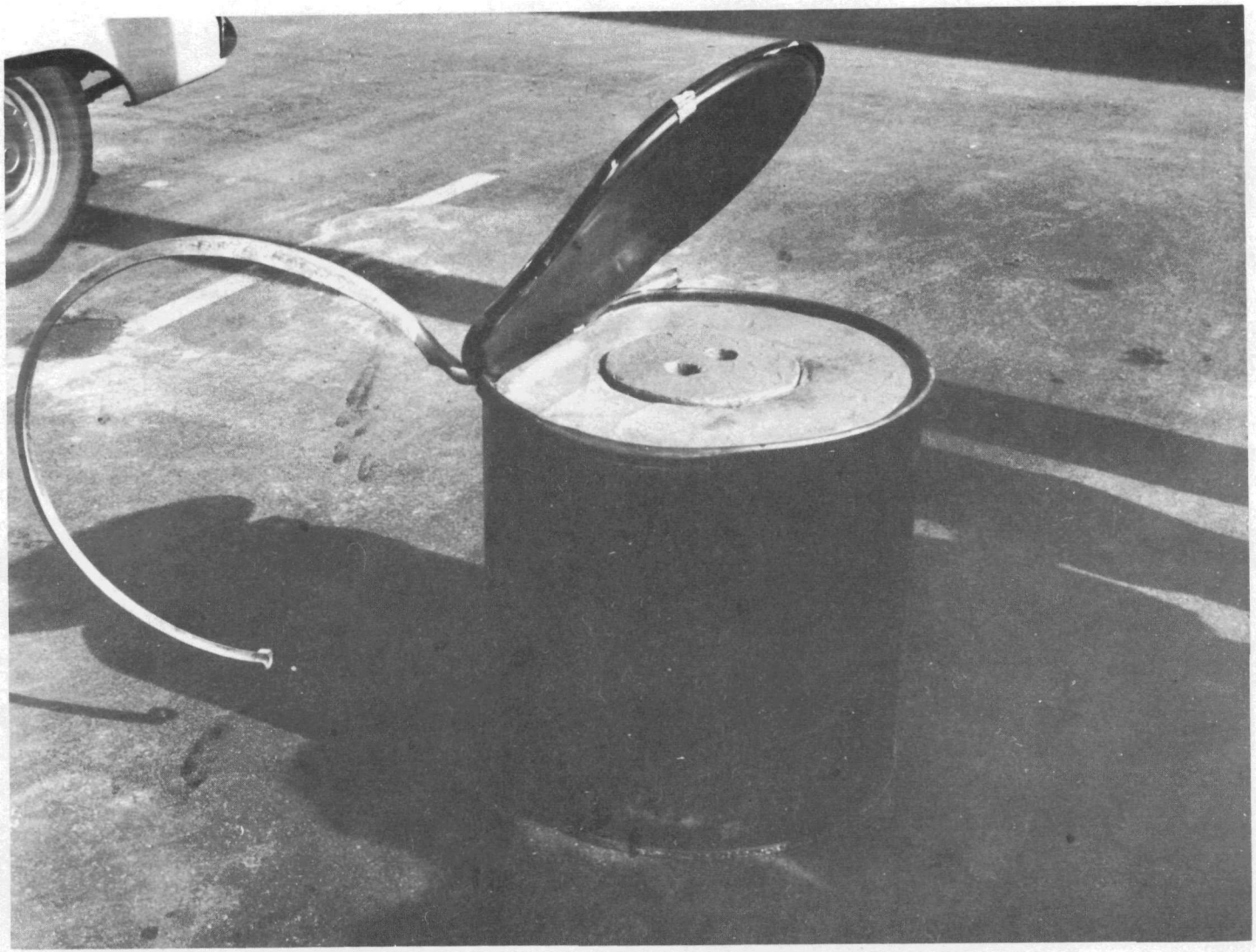


Figure 13. OPEN DRUM AFTER TWO DROPS.

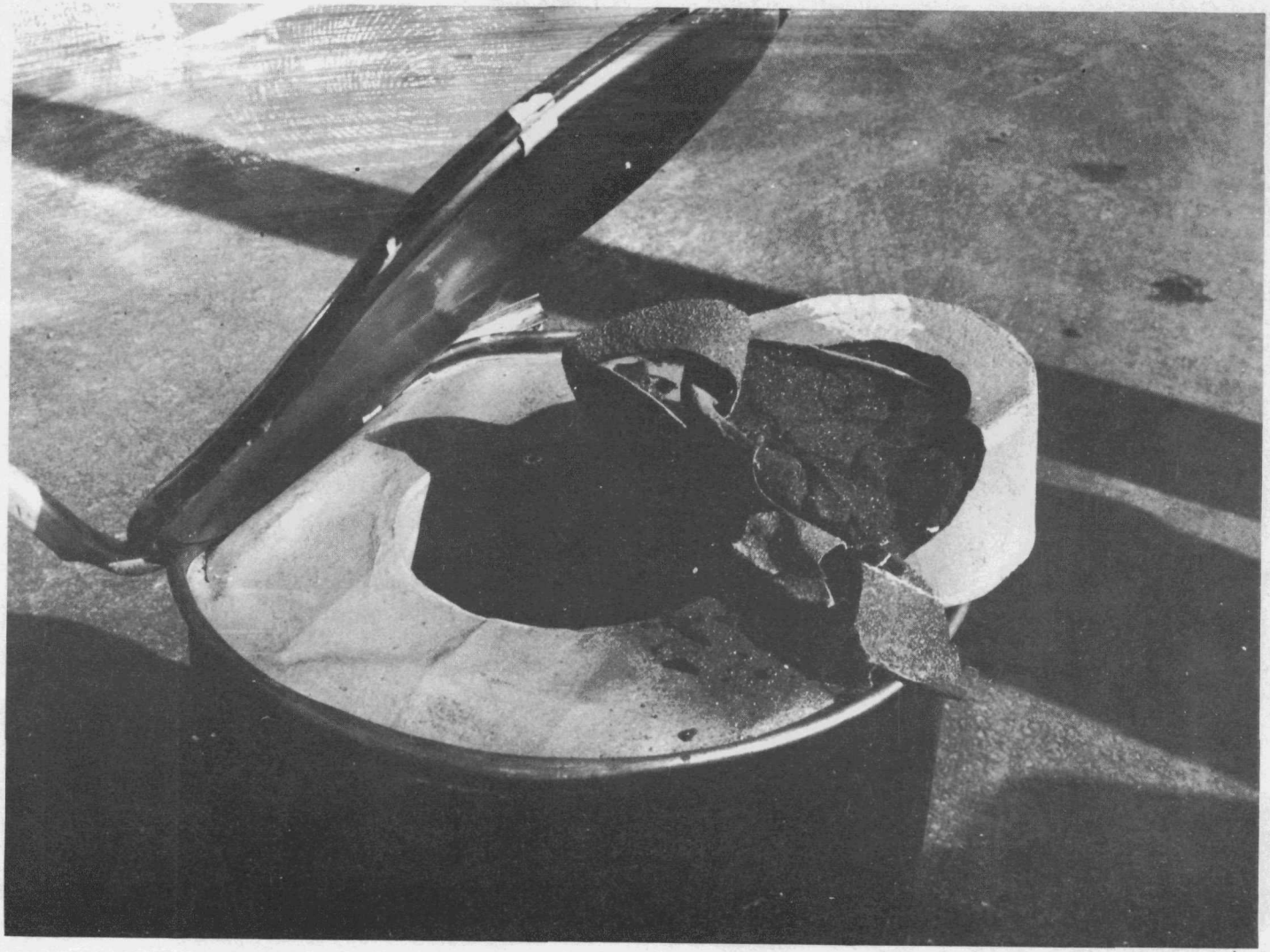


Figure 14. PLUG AFTER TWO DROPS. (Coating Opened by Hand to Show Foamglas)

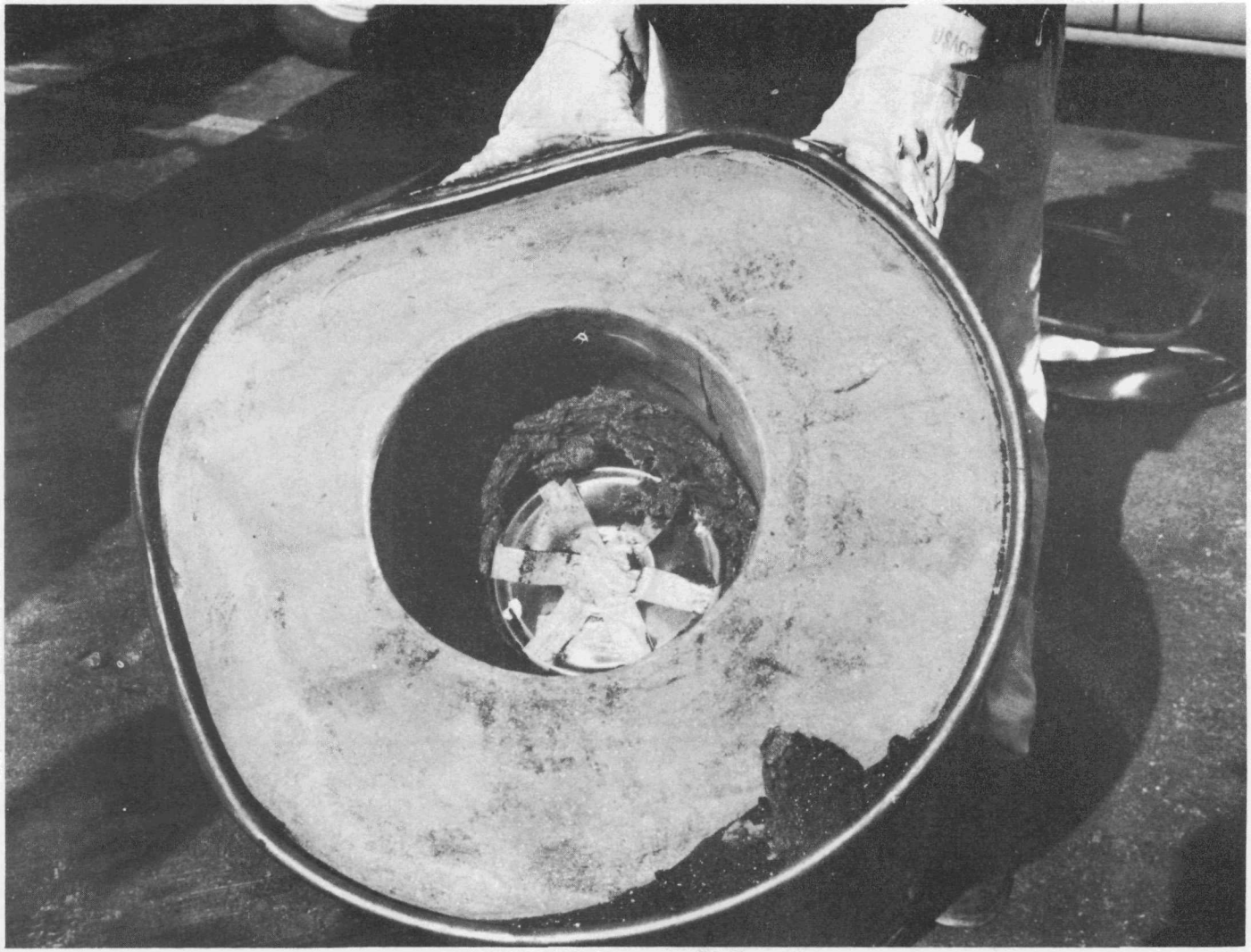


Figure 15. INSIDE OF CONTAINER AFTER TWO DROPS. (Note Can in Cavity)



Figure 16. INTERNAL DEFORMATION CAUSED BY HOSPITAL CAN. (Deformation about One-Inch Deep)



Figure 17. VIEW OF FOAMGLAS SURFACE, IMPRINT, AND UNDAMAGED LOAD. (Internal Coating Exposed to Show Foamglas Surface and Impact Imprint)

3. The bolted ring clamp did not fail under direct impacts. The closure is thus considered adequate.

4. The effects on the nuclear safety of a permissible shipping array due to reduction in container volume is considered negligible, when compared to the suggested safety factors.

COMPLIANCE WITH CRITICALITY REQUIREMENTS FOR SHIPMENT

The original objective of providing nuclear safety at least as good as that experienced with 20-inch birdcages is met by the proposed container. Briefly, this means that, in accordance with the Nuclear Safety Guide,(5) 50 units, each containing 18.5 kilograms of U-235 as metal ($H/X < 0.5$), may be transported as a controlled shipment. In the case of uncontrolled transportation, the same limits hold except the loading is reduced to 9.5 kilograms of U-235. Actually, because of the increased volume of the drum, 65 units could be shipped under these rules.

For international shipments, the proposed container meets Class II requirements.(6) Thus, 50 units containing 5.0 kilograms of U-235 metal could be shipped at one time. It is also of interest that flotation gear would not be necessary since the loaded container would float freely. It is conceivable that, with additional design modifications, the subject container can be made to conform to Class I requirements. The major factors involved are neutron moderation and absorption of such nature that effective isolation is accomplished. Further thought will be given to this possibility.

ACKNOWLEDGEMENTS

The cooperative efforts of members of the Chemical and Development Divisions are acknowledged with particular recognition of the contributions of J. W. Strohecker.

REFERENCES

(1) Military Specification MIL-C-4150.

(3) Draft Revision of the Interstate Commerce Commission Regulations Pertaining to the Rail Transport of Radioactive Materials, August 1, 1962.

(4) Code of Federal Regulations, Title 10, Part 71, Regulations to Protect Against Accidental Conditions of Criticality in the Shipment of Special Nuclear Material, Draft Revision, November, 1962.

(5) Subcommittee N6.8, American Standards Association, TID-7016, Nuclear Safety Guide, 1961.

(6) International Atomic Energy Agency, Regulations for the Safe Transport of Radioactive Materials, Safety Series No. 6, Vienna, 1961.

DISCUSSION AND COMMENT

With respect to the standard fire test and temperatures from the standard fire test, Mr. McLendon's discussion indicated that an attempt was made to have the shell of the container follow the standard time-temperature curve. The shell temperature of course will depend on the character of the container as well as on the character of the fire.

In the case of one large cask, two analyses have been made. One assuming that the skin temperature of the cask followed this time-temperature curve, and the other assuming that the flame or that the atmosphere in the furnace followed this time-temperature curve, let the temperature of the cask be what it may. The first assumption, that the skin followed this curve, is much more severe and resulted in roughly 50 per cent more heat getting into the cask than if one assumes that the ambient atmosphere followed this curve. One understanding of the standard fire test is that the material in the furnace at the start of the test is 1700° Fahrenheit. Thermocouples are placed close to the object being tested. The thermocouples defined in the Underwriters' handbook are of a particular type inside a one inch diameter pipe and placed in a particular position. This time-temperature curve is the temperature recorded on the thermocouples. It bears no direct relationship to the flame temperature and no direct relationship to the skin temperature of the object being tested.

This is one of the uncertainties with regard to the characteristic of the standard fire that should be resolved before we can make really good calculations regarding what happens to the cask in the fire.

With respect to an accidental fire, we are familiar with ASTM test procedures. The questions that were just raised with regard to the standard tests can be explained this way:

In developing these standards a considerable number of tests were conducted on actual building fires. Temperature measurements were made in these buildings and the method of enclosing the thermocouple was similar to that that is prescribed currently in NFPA and the NFPA testing procedure. So in characterizing your fire you have to consider that the method of measuring the temperature in the furnace. In other words, the temperatures in the furnace during the early part of the test will be higher than those indicated by the thermocouple because of the use of the iron pipe that surrounds the thermocouple.

With reference to the drop tests of the bird cage, there was no additional work, such as stress relieving, done on the welds. Actually, the bird cage itself was not fabricated in accordance with the design we developed which, as I say, was copied from the early Hanford days. The welder was kind and instead of making skip weld he actually welded as much as he could of that central container to the diagonal braces. So we had a better device than was shown on the drawing.

In the 30-foot drop test, the information on spacing is a little different than in the proposal where we only allow 10 per cent deformation.

The drop test on the case in use at the moment was done so that all of the bird cages would deflect in approximately the same manner. We know the safety factors built into this bird cage and still have space relationships that would not cause a critical mass to be generated.

In the experience at Savannah River and at Rocky Flats, 10 per cent allowable deformation is a fairly small number. More typical is something like 30 to 35 per cent or more. Now, if we are imposing upon these stringent requirements, well and good, but why? All of those who are concerned with criticality certainly take into account that this deformation is part of the consideration.

Does 30 miles per hour cover the average speed of a passenger train or should we say 60?

The test conditions of 30 mph were given to us. Hauls of this type are made in a passenger train which might go 70, 80, or 90 miles an hour. As I say, somebody mentioned yesterday they have adopted the standard 30 foot drop which is 30 miles an hour, if you calculate it. We just did what we were asked to do in this case.

It was noted that the wire mesh required by the Bureau of Explosives has nothing to do with protecting the contents of the container. The wire mesh is to prevent the telescoping of packages, one within the other, rather than to protect them from impact. In an impact, of course, the bird cage or almost any other package we might have will be distorted.

From a practical point of view we think if all of the central portions of the packages would shift, they would all shift pretty much together under impact, so they would probably be somewhere near the same distance apart. We hope your calculations have not been such that if there were some failure on the part of the package that we would necessarily have a nuclear excursion. The bird cage has not been one of our favorite packages.

Session Chairman: The next paper is a description of a plutonium and enriched uranium shipping container and integrity tests on this container. The paper will be given by Mr. C. L. Schuske of the Dow Chemical Company.

DESCRIPTION OF A PLUTONIUM AND ENRICHED URANIUM SHIPPING CONTAINER AND INTEGRITY TESTS ON THIS CONTAINER

by

C. L. Schuske

THE DOW CHEMICAL COMPANY
ROCKY FLATS DIVISION
DENVER, COLORADO

U. S. Atomic Energy Commission Contract AT(29-1)-1106.

ABSTRACT

The M-101 (an all steel) shipping container and safety cage has been in use for about 15 years for transporting and storage of enriched uranium. With slight modifications and the addition of an inner container, the M-101 can be used to ship plutonium metal. This paper describes various physical tests performed on the M-101 and inner container and also discusses critical array sizes under various conditions of spacing and flooding.

INTRODUCTION

Although the M-101 has been used for 15 years without incident in the transport of enriched uranium, we recommend various modifications to this container for the handling of plutonium metal. Because of the toxicity of plutonium, better containment is desirable.

The suggested modifications to the M-101 consist basically of replacing a Neoprene gasket with a stainless steel "O" ring and removing a gauge and stopcock from the container lid. These changes result in a very fire resistant carrier. In addition, extra safety for plutonium is accomplished by adding an inner container. This inner container will retain plutonium metal or oxides under the adverse conditions that might be expected in a transport accident and resulting fire.

Figures 1 and 2 are exploded views of the modified M-101 and inner container.

Dow Drawing 2-7552-76A defines M-101 modifications and inner container design. Other points of interest are:

1. The M-101 and inner container are of all steel construction. Containment of contents is accomplished by the use of pressurized stainless steel "O" rings in both the M-101 and inner container.
2. The M-101's approximate weight is 85 lbs. The inner container is approximately 50 lbs. The total weight is 135 lbs.
3. The cost of the M-101 is $126.00. The inner container cost is approximately $100.00. The total cost is approximately $226.00.

INTEGRITY TESTS

Although the M-101 container was designed more than 15 years ago, very few physical tests were performed to determine the integrity of this container under serious accident conditions. The tests previously performed were vibration tests. These tests fairly well established the strength of welds and construction under conditions which would lead to fatigue of its components.

The M-101 has held up well over the many years of its use. Recent thought was given to certain required changes to this system that would extend its possible use to plutonium as well as enriched uranium.

Due to the toxicity of plutonium, it was felt the containment under a serious transport accident such as collision and fire would be necessary.

The modification to the M-101 and the inner container addition are given in Dow Drawing 2-7552-76A.

The requirements were as follows: Containment be maintained under the following contingencies, severe collision, impact velocity of the M-101 case and contents of approximately 130 ft/sec, followed by oil fire.

The tests were conducted on the modified M-101 and inner container that contained a simulated load (in this case, lead.)

TESTS PERFORMED ON MODIFIED M-101 AND INNER CONTAINER

Drop Tests (1)

Drop tests were performed on a modified M-101 and inner container. The container with store was dropped onto a concrete pad on a cage corner from a height of 13 feet, and again from 19 feet. Peak accelerations recorded along the direction of impact were 310 and 350 g respectively. A third and final drop of 250 feet from a tower onto a concrete pad was performed. The M-101 was dropped lid down for maximum damage.

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(1) W. M. Sigmon, J. E. Bear, R. S. Hooper, "Drop Test of an M-101 Carry Case and Simulated Store." T-18725, 5-22-62.

The outer framework of the cage was bent, however, the overall volume defined by the framework was compressed less than 20%. The central container and inner container were only slightly scarred and no leaks occurred in these containers as a result of these tests. The tests revealed that the container could have survived a considerably more severe drop test.

Fire Test [2]

An ignited pool of fuel oil was used to determine the fire resistance of the M-101 and inner container. The maximum temperature developed in the inner container during a 30-minute fire was 1600 F or 870 C. The M-101 and inner container were not damaged in this test.

The Metallurgical studies (reported elsewhere in this report), indicate that the 0.5 in. thick steel inner container is sufficiently durable to withstand an oil fire that could occur as a result of an accident. In addition, the outer container of the M-101 will add a second line of containment.

Molten Plutonium Penetration Study on Steel Inner Container [3]

Since molten plutonium readily forms low melting eutectics with iron, it was desirable to test materials out of which the inner steel container was manufactured. This study consisted of using a steel thimble 4 in. long and 2 in. in diameter with 0.5 in. thick walls as the test vessel.

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(2) J. Q. Lilly, J. E. Bear, R. S. Hooper, "Simulated Aircraft Fire Test on a M-101 Carrying Case and Store". T-18710, 5-16-62.

(3) C. E. Wickland, "Investigation of Steel as a Shipping Container for Plutonium". Metallurgy Group Memo 41. The Dow Chemical Co., Rocky Flats Division, Denver, Colorado.

Plutonium metal was placed into the thimble and heated in an induction furnace to arrive at the temperature that could be expected from an oil fire which is about 870 C or 1600 F. Molten plutonium held for 30 minutes at 900 C and molten for approximately one hour will penetrate the steel inner container an average of 1/8 in. with a maximum penetration of 3/16 in. as determined by sectioning the test vessel and making metallographic determination on these test sections. These conditions exceeded the test requirements (inner container temperature of 860 C for 30-minutes) and indicate that the 0.50 in. walled inner container will retain plutonium as per the test requirements.

Equilibrium Temperature of Plutonium in Shipping Container (under normal conditions) (4)

Due to alpha heating of plutonium, some care should be observed in the packaging of plutonium for storage and transportation. It is desirable that the packaging have a minimum of thermal insulation. Heat build up can present operational problems in the removal of the material from the package. It was thus felt desirable to study this effect for the M-101 arrangement. Experimental and Theoretical studies performed on 4 kg of plutonium buttons indicated that the equilibrium temperature of plutonium in the M-101 and inner container will not exceed 50 C.

These tests indicate that the heat build up under normal operating conditions will not present any additional handling hazards.

CRITICALITY CONSIDERATIONS

The following contingencies were considered in arriving at a safe number of containers (plutonium) for shipment.

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(4) G. D. Hartert, "Equilibrium Temperature of Plutonium in Shipping Containers". May 11, 1962.

1. Assumed accident sufficiently severe to strip outer cage from the M-101 central container which in turn contains the inner container. (Drop tests indicate that this assumption is grossly conservative.)
2. An array of central containers come together to form a pseudo-cylinder.
3. The array of these containers will be moderated with an optimum amount of water.
4. The array of central containers will be infinitely reflected with water or earth.

Results of the calculations indicate that under the above conditions more than 100 containers, each containing 4 kg of plutonium or 18 kg of uranium would be required to become critical. We recommend 50 containers as a conservative number per shipment.

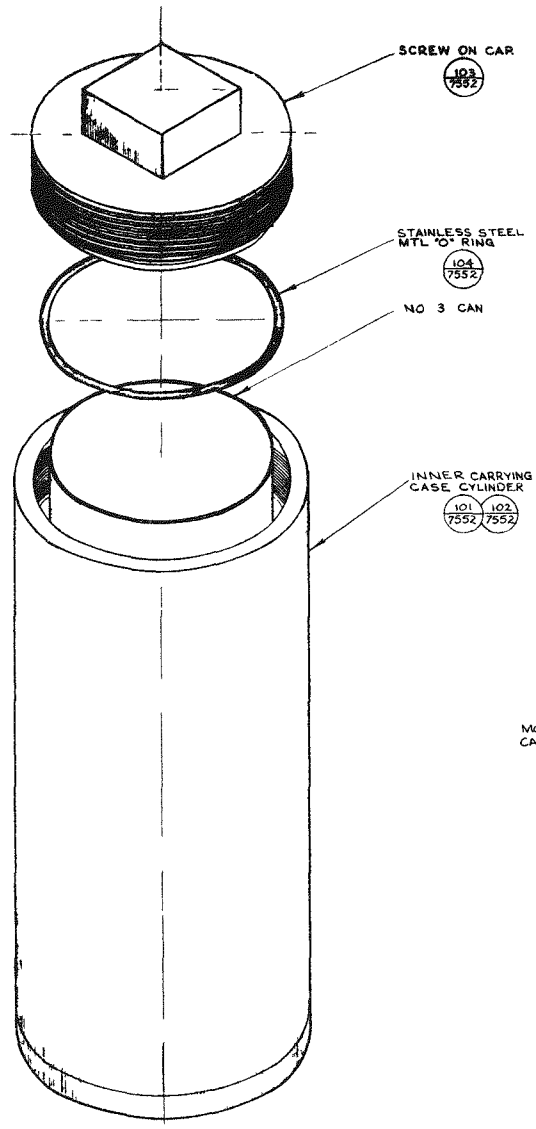
The drop tests indicate that the actual array lattice resulting from a serious collision would be considerably greater than that assumed in the above analysis, thus the critical number of containers would be several times greater than 100.

CONCLUSIONS

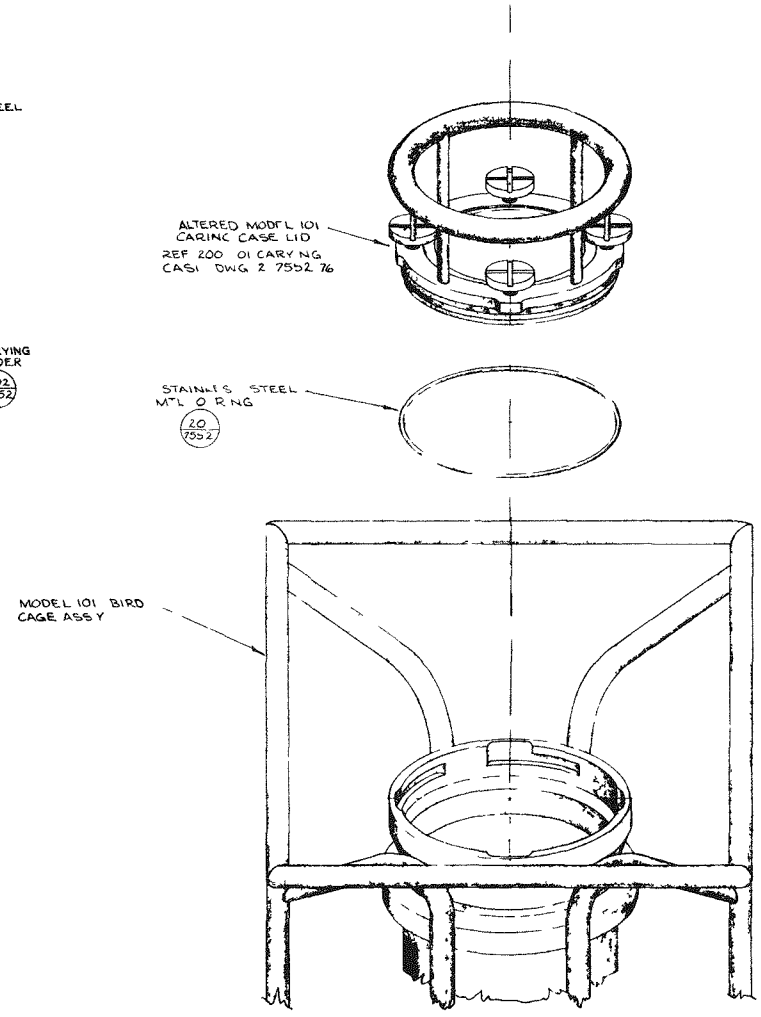
The results of the tests indicate that the modified M-101 and inner container are more than adequate to ship plutonium and enriched uranium metal safely.

ACKNOWLEDGMENT

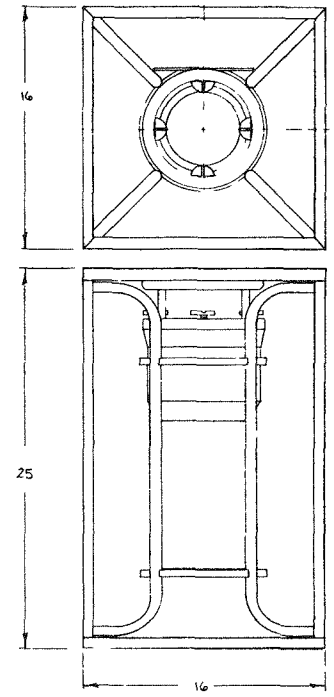
The author acknowledges the contributions to this report of work and results provided by the Sandia Corporation, Albuquerque, New Mexico, and Rocky Flats personnel from the Chemical Engineering, Metallurgy Technical Staff Groups, and Mr. D. W. Park of Tech. Staff Engineering.



EXPLODED ASSEMBLY
FIGURE 1
SCALE ¾ = 1



EXPLODED ASSEMBLY
FIGURE 2
SCALE ½" = 1"

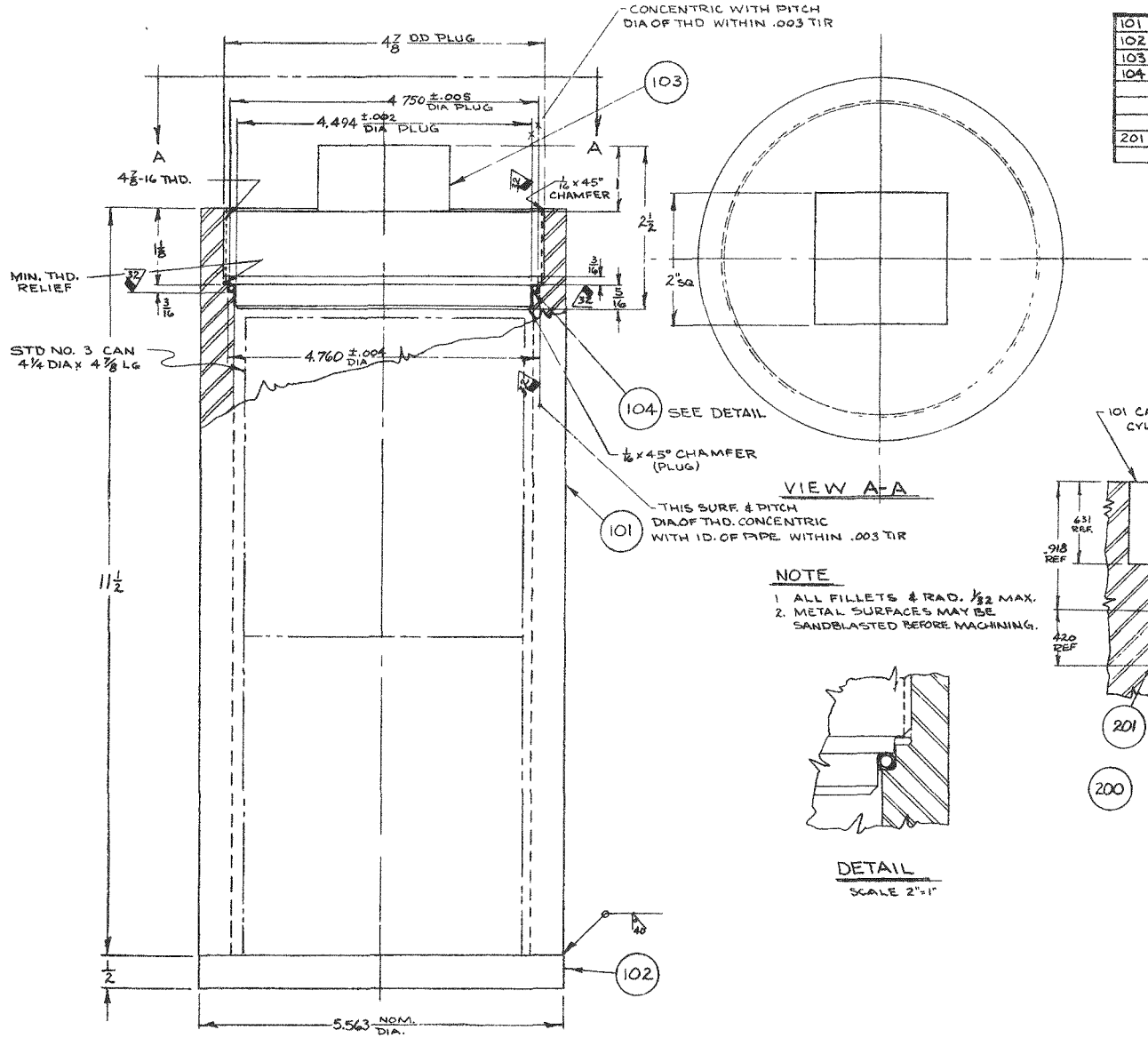


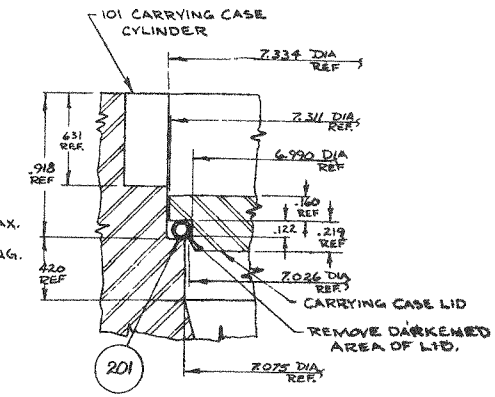
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REF DWGS
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1P20070
2 7552 76
7745 76

CARRYING CASE
PICTORIAL
DWG. NO. 1-7745-76

101	1	PIPE 5" SCH. 120 (½ W) X 11½ LG	1020 S/L
102	1	SHEET ½ X 5 3/8 SQ.	" "
103	1	BAR 5 DIA X 2½ LG	" "
104	1	MTL "O" RING 4.750 +.005 -.008 OD X .125 +.002 -.003	321 S/S
		TUBE, PRESSURE FILLED,	4750-7 3-PF
		(THE ADVANCED PROD. CO.)	
201	1	MTL "O" RING 7⅛ NOM OD. X ⅛ NOM TUBE	321 S/S
		PRESSURE FILLED (THE ADVANCED PROD. CO.)	7250-7-PF





200 101 CARRYING CASE ALTERATIONS

SCALE 2"=1"
ALL DIMS WITH "REF" WERE OBTAINED BY DIRECT MEASUREMENT OF A 101 CARRYING CASE.

CARRYING CASE ASS'Y - DETAILS
DWG. NO. 2-7552-76B

Remarks by Mr. Schuske: Mr. Alan Grange of the UKAEA performed a series of five integrity tests on the M-101 and inner container. These tests were in addition to the integrity tests performed on this container by the U. S. and reported earlier.

The object of the tests, with respect to normal conditions of transport, including minor mishap and the "Maximum Credible Accident", was to:

a. ascertain whether the features of the packaging designed to provide containment are adequate to prevent any loss or dispersal of the contents.

b. determine the effectiveness of the features of the packaging provided for the purposes of criticality control (namely the cage).

The tests should demonstrate:

a. whether rain water could penetrate the lid of the outer container and fill the space between it and the containment vessel (inner container).

b. in the event of penetration, whether water would penetrate into the containment vessel itself.

c. whether the vibration in the transport environment would be likely to result in the "bird" becoming detached from the "cage".

d. how the spacing afforded by the cage would be distorted and effectively reduced both as a result of an accidental impact and a severe fire immediately following such an impact.

e. whether an exposure to the fire and action by a fire fighting unit would result in ingress of water to the outer and inner container.

Tests conducted on this container were as follows:

1. A heavy spray of water was directed against the M-101 to simulate a driving rain. The duration of this test was two hours. One hour on one side and the second hour on another side.

   Result: The bird did not leak.

2. The M-101 was mounted on a shake table and vibrated to simulate road vibration.

   Results: Several welds cracked and one of the supporting tubes of the frame cracked. These cracks indicated that the

welds had not been stress relieved after welding. Stress relieving would seem necessary. (The cage was rewelded for the drop tests.)

3. The M-101 was then dropped from a height of 30 feet onto a steel rail. The rail consisted of a stiffened steel plate 1 in. thick and 1 foot wide, by approximately 40 in. long. The cage was dropped astride the 12 in. width of the rail.

   Result: The blow delivered to the cage resulted in a bending action to the cage and produced a dent, maximum depth of 1/2 in., to the "bird".

   The over-all volume of the cage was reduced to 67.5% of its former volume.

4. Following the drop test, the M-101 was placed into a furnace and heated at 800° C for 30 minutes.

   Results: The lead placed in the containment vessel for the test did not leak out, indicating that the inner container was secure.

5. The M-101 was then placed in a water well to determine if the "bird" would take on water under the condition of total immersion.

   Result: The immersion test indicated that the "bird" did leak but the primary containment (inner container) did not leak.

The results of these tests were then reviewed by Mr. Alan Fairbairn, Head of Chemical Plants and Laboratories Section, Safeguards Division, UKAEA.

Mr. Fairbairn, in his letter dated November 19, 1962, "M-101 Transport Packaging", reported that the M-101 packaging is up to the standard required to resist the "Maximum Credible Accident", that is, Type B containment.

He and Mr. Edward Woodcock, of the UKAEA Health and Safety Branch, indicated that under Class II of the IAEA Annex III, Safety Series No. 6, as many as 40 packages, each containing 7-1/8 kg of Pu or 16 kg of enriched uranium would be safe in a single shipment.

These calculations included the over-all loss in volume of the cage due to the "Maximum Credible Accident", and the leakage of the "bird", and the fact that the inner container did not leak.

Mr. Fairbairn also indicated that it may be possible to ship enriched uranium appropriately wrapped in the "bird" if future tests indicate that adequate containment is possible without the inner container. However, to classify the M-101 as a Class B package for plutonium shipments, the inner container would be required.

STATIC AND IMPACT TESTS ON A FULL-SCALE, IRRADIATED FUEL SHIPPING CASK

BY

WAYNE I. THISELL

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ENGINEERING DEPARTMENT

WILMINGTON, DELAWARE

ABSTRACT

A 15-ton, lead-shielded steel cask used for rail shipment of irradiated fuel was subjected to static and impact tests. The tests are described and results are summarized.

I. INTRODUCTION

This paper covers the results of non-destructive static and destructive dynamic tests on a full-size 15-ton lead-shielded steel cask used for shipping irradiated atomic reactor fuels.

The U.S. Atomic Energy Commission authorized this work to determine the structural integrity of a specific and fairly representative cask with respect to the type of impact that might be encountered in a shipping accident. A longer range objective is extension of the results to casks of other designs, and development of reasonable methods of design to provide specified impact resistance.

The design analysis of casks of this type is so complex and theory so lacking, particularly when confronted with dynamic conditions, that model and prototype tests are fully warranted.

II. DESCRIPTION OF CASK

The cask was originally designed for rail shipment of Savannah River Plant fuel to Idaho Falls, Idaho and was one of four fabricated by Knapp Mills, Inc., Wilmington, Delaware in 1955. It is anchored to the railroad car during transit (Fig. 1) by means of a special frame and tie rods. After years of service, it was decontaminated and made available for testing.

The cask (Fig. 2) is essentially a rectangular box with a bolted-on cover and weighs approximately 15 tons. A cavity for containing the fuel elements is formed in the main body by an inner steel shell which is separated from the outer steel shell by 8-1/2 ins. of lead shielding. Homogeneous bond between lead and steel was specified to insure good heat transfer through the cask wall. Vertical cooling fins are spaced at 2-in. intervals around the periphery of the outer shell.

The cover consists of inner and outer steel shells separated by a minimum of 8-5/8 ins. of lead at the center. The cover's outer shell is reinforced with stiffener plates and 3-in. T-beams which span the short dimension, herein called the north-south direction.

To insure homogeneous bond between the lead and steel, the bonding surfaces of the steel were tinned before pouring the lead. Both the body and cover were in an upside-down position when the lead was poured through the pouring openings in the bottoms of the respective parts. After pouring, the openings were covered with 1/2-in. plate which was welded in place with a final closure weld.

Prior to the static tests the bond was checked by ultrasonic means. Rather large areas of no bond were found near the bottom of the north and west sides. Due to the pouring method, there was no bond on the bottom of either the body or cover.

Using the total contact area of lead and steel as a base, it was found that 72 percent of the lead surface area was bonded to steel. This was approximately the same as was found when the cask was originally fabricated, and it was concluded that the bond had not changed during the years that the cask was in service.

A significant portion of the non-bonded area consisted of the bottoms of the body and cover which, due to the pouring method, could not be bonded. Eliminating these areas from consideration, 91 percent of the remaining lead surface area was bonded.

It was decided before commencing the static tests that the six existing 1-1/2-in. studs fastening the cover to the body were not adequate. To prevent premature termination of testing due to bolt failure, 12 studs were added.

A picture frame of 4-in. by 1-in. plates which projected into the body cavity was welded to the bottom of the cover. This was close-fitting in the cavity and insured that the bolts would not be loaded in shear. Guides and separators in the cavity were removed during the decontamination operation.

III. STATIC TESTS

A. DESCRIPTION

The static compression tests were conducted by the Fritz Engineering Laboratory, Lehigh University, Bethlehem, Penna., using a 5-million-pound capacity Baldwin universal testing machine.

The static tests were intended to provide information which would help decide in which attitude the cask should be dropped to produce maximum damage and to provide data which might be correlated with that obtained in the drop tests.

The following tests were conducted:

Test 1 -	Concentrated Load through Trunnion Axis	(Fig. 3)
Test 2 -	Distributed Load on Cask Sides	(Fig. 4)
Test 3 -	Distributed Load Between T-beams	(Fig. 5)
Test 4 -	Distributed Load on T-beams	(Fig. 6)
Test 5 -	Load Concentrated on bottom over 6" Diameter Area	(No Fig.)
Test 6 -	Diagonal Load Distributed Short Edge	(Fig. 7)
Test 7 -	Diagonal Load Distributed along Long Edge	(Fig. 8)

Test 8 - Load Concentrated on Diagonally Opposite Corners (Fig. 9)

Strain in the steel was measured by 78 SR-4 strain gages attached to inside and outside surfaces of the cask. Internal deformations were measured by three linear transducers mounted inside the cavity and connected to a Brush recorder. Five Ames dial gages measured external deformations.

Compressive load was applied in increments until one or more strain gages indicated that the steel at that location had been strained to more than 0.10 percent (30,000 psi). The load was held constant for about twenty minutes at each increment while the strain and deflection gage readings were recorded.

B. RESULTS

These tests showed:

(1) The cask is most vulnerable to a punching load on the bottom.

(2) The cask is least vulnerable to diagonal loads applied to the edges or corners.

(3) Bond between lead and steel does not change when strains do not exceed those of the tests (say 0.15% strain).

(4) The cask acts in a plastic fashion, suggesting high capacity for absorbing energy.

Figure 10 indicates the plastic nature exhibited by highly-strained gages in all of the static tests. A very definite curvature is apparent in the load-strain diagram, even at relatively low (for steel) strains, and significantly large permanent strains exist when the load is removed. Reloading causes the plot to follow back up the unload curve to the point of maximum previous load and then resume the original path as loading is continued. This action is duplicated again and again at higher loading.

It is believed that an explanation for such action is this:

The lead and steel deform when load is applied; when the load is removed, the steel tries to return to its original position but does not possess

enough energy to move the lead with it so they both remain in the deformed condition. It should be noted that a check by ultrasonic means before and after testing showed that the bond between the lead and steel had not changed. If bond had been destroyed, the steel in some locations would have been free to return to its original condition.

IV. DROP TESTS

A. DESCRIPTION

Five free-fall drop tests with impact velocities of 10 to 30 mph were conducted at The Budd Company, Philadelphia, Penna. The following tests were conducted:

Test 1 - 7-1/2 ft. drop - flat on bottom

Test 2 - 15 ft. drop - flat on bottom

Test 3 - 30 ft. drop - flat on bottom

Test 4 - 3-1/2 ft. drop - flat on the end of a 6-in. diameter steel shaft

Test 5 - 30 ft. drop - on short bottom edge

Only the height of drop was changed for the first three tests to provide maximum correlation of test results. The flat bottom attitude was chosen for those drops since it would produce maximum decelerations, would lend itself to theoretical analysis and was least likely to distort the cask to such an extent that further tests would be prevented.

A drop tower (Fig. 11) about 50 ft. high was erected on a reinforced concrete slab supported on soil with a bearing capacity of 6000 pounds per square foot. Centered under the drop tower was a 9-in. thick steel armor plate anchored in the concrete slab. The combined weight of slab and plate was about 7-1/2 times that of the cask.

Nine strain gages, mounted on the cask interior and exterior, were monitored with cathode ray oscilloscopes equipped with oscilloscope cameras.

Three piezoelectric shock accelerometers (Endevco Model 2225) rated at 10,000 G's were mounted on the cask; one inside on the bottom of the cavity, one outside near the bottom of the west side and one at the top center of the cover on the outside.

Each drop test was recorded with two high-speed 16 mm cameras located about 50 feet south of the impact area. One camera, left-of-center, operated at speeds up to 4000 frames per second, and the other, right-of-center, operated at speeds up to 2000 frames per second. These were edited and spliced into one continuous film after testing was completed.

For Tests 2, 3 and 5 a fixed point in space was obtained by hanging a graduated, 16-in. long 2 by 4 from the drop tower by rubber bands. This device had a natural frequency of 0.80 cycles per second and remained essentially stationary until after the maximum dynamic deflection of the slab had occurred. Using this as a reference, it was possible to approximate the maximum dynamic deflection of the slab from the movies.

B. RESULTS

The modified cask performed well, considering the severity of the tests. The drop tests did not cause it to burst open or deform to an extent that would cause great concern. The cover was removed without difficulty after each drop and after the final drop the cavity was filled with water with no apparent leakage. It is believed the modifications to the bolting and cover influenced the results.

The cask exhibited a large capacity for absorbing energy in a plastic manner with very little rebound after impact. This is confirmation of the plastic action observed in the static tests.

The permanent deformations of the cask were similar to those observed on models dropped by the Franklin Institute, Philadelphia, Penna., and it is believed that model testing holds promise for developing theoretical analysis and empirical rules for design.

It may be seen (Fig. 12) that decelerations measured in the flat bottom and edge drops were approximately linear functions of drop height. Also shown are the decelerations recorded in tests of other objects. This shows that a wide range of decelerations may be obtained, depending upon the object dropped, its attitude at impact and the relative stiffness of the surface against which it is dropped.

It is clear that different portions of the cask are subjected to different decelerations. This is due to the variation in time required in bringing to rest each particular element of the structure. Lower parts are brought to rest more quickly and the peak deceleration is high.

Figure 13 illustrates the crushing of the edge caused by the 30-ft. edge drop. The bottom edge of the cask came to rest in 5-1/2 ins. (crushing) plus about 1/2-in. dynamic deflection of slab. This helps to explain why the decelerations of the edge drop were so much lower than the flat-bottom drops.

Piercing of the cask bottom was easily accomplished at a velocity of only 10 mph, as was illustrated by the 3-1/2-ft. drop on the end of a 6-in. diameter shaft. The puncturing end of the shaft was machined square with a 1/16-in. radius at the edge.

The shaft easily sheared the 1/2-in. thick outer shell and penetrated the bottom to a depth of 1-5/8 in. (Fig. 14) before coming to rest. The cask remained supported on the shaft and a force of 10,000 lbs. was required to remove it. A 12-in. long crack developed in the closure weld on the bottom on the south side.

Following the puncture test, holes were drilled just below the top flange of the cask body and no evidence of lead settlement was found at this level. Ultrasonic inspection showed that there was no change in bond between lead and steel anywhere in the cask.

A study of the data indicated there is no correlation between drop height and dynamic and permanent strains. The results are very inconsistent with the strains changing from compression to tension and back again for different drops. This suggests that strains in other parts of the body have a significant effect on the strain in the locality of the gage.

This lack of strain gage correlation may be due to yielding in the structure causing it to act in a different manner under increasing load. The gages in many cases showed strains beyond the elastic limit and in some cases beyond the useful range of the gage. Correlation between drop tests might be found if tests were conducted with small increments of drop height.

Figure 15 shows on a sectional elevation the progressive permanent distortion of the cask measured after the flat bottom drops. The deformations are exaggerated 10:1 in the horizontal direction and 2:1 in the vertical direction. This shows clearly that the height of the cask body was significantly reduced and a considerable bulge occurred at the bottom. The bulge is assumed to have been equally distributed to each side. The greater reduction of height on the north side indicates that it was subjected to more impact than the south side, particularly in the last test.

The outward bulge of the cavity suggests that the lead did not act like a fluid under the dynamic load since fluid loading would tend to deflect the cavity inward. It seems probable that the lead moved in the direction of least resistance (toward the outside) and still bonded, pulled the inner shell along. Thus a composite action occurs.

Figure 16 is a sectional plan showing the maximum distortion of the inner and outer shells. The maximum distortion of the outer shell occurred 6-3/8 in. above the bottom of the cask and that of the inner shell was 4 ins. above the bottom of the cavity. It appears that the amount of distortion is roughly proportional to the drop height.

After the 30-ft. edge drop, a crack in the lower section of the northwest edge exposed the lead. It is believed that the previous drops were a contributing factor to this. The edge drop also opened up the bottom closure-weld crack which was developed in the punch test.

V. SUMMARY OF RESULTS

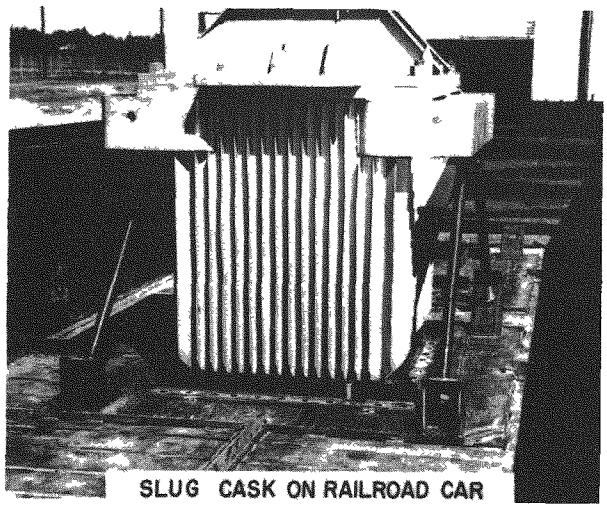
These tests showed:

A. The modified cask suffered only relatively minor external damage from impact against a flat surface at velocities up to 30 mph.

B. Relatively little damage occurs because the plastic action of the lead absorbs the energy of impact. There is evidence which suggests bond between lead and steel is important in this action.

C. The modified cask is most vulnerable to piercing or punching through the shell, and it is in this manner the contents could be released most easily.

(Text continued on page 210.)



SLUG CASK ON RAILROAD CAR

Figure 1

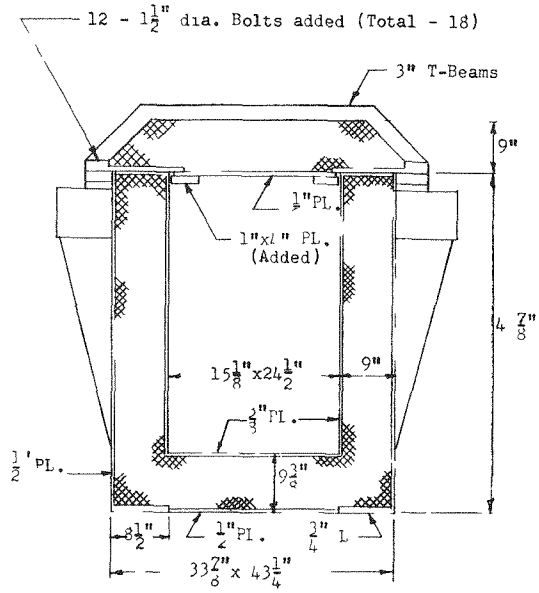


Figure 2

Modified Cask



Figure 3

Test No. 1

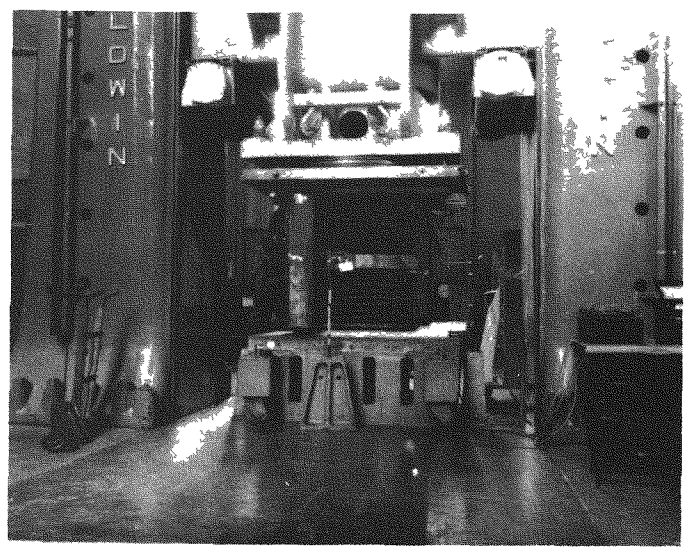


Figure 4

Test No. 2

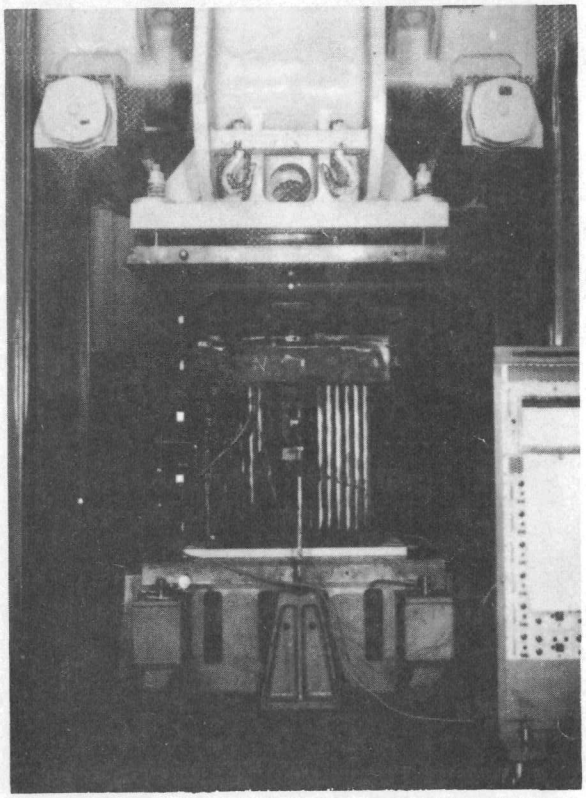


Figure 5 Test No. 3

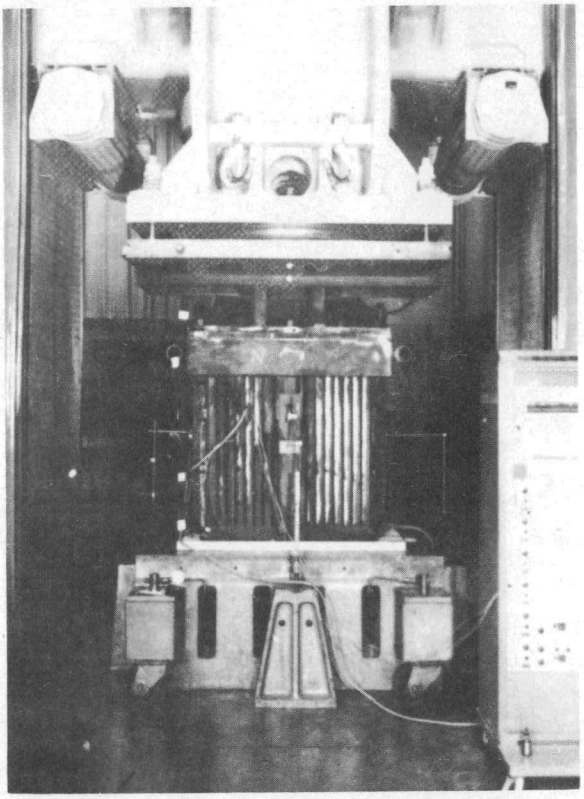


Figure 6 Test No. 4

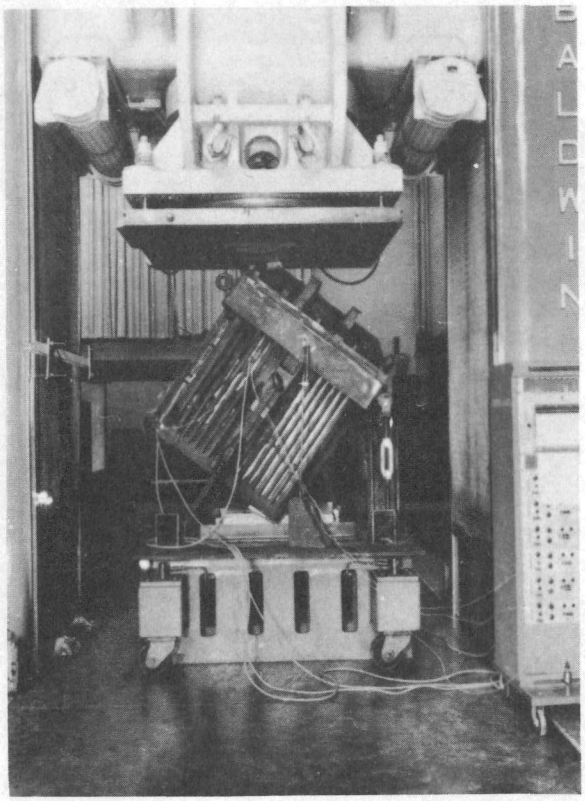


Figure 7 Test No. 6

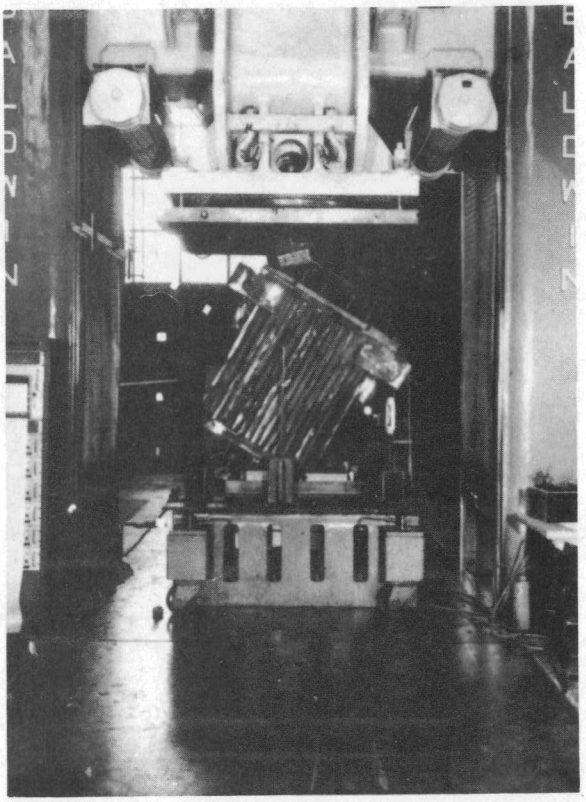


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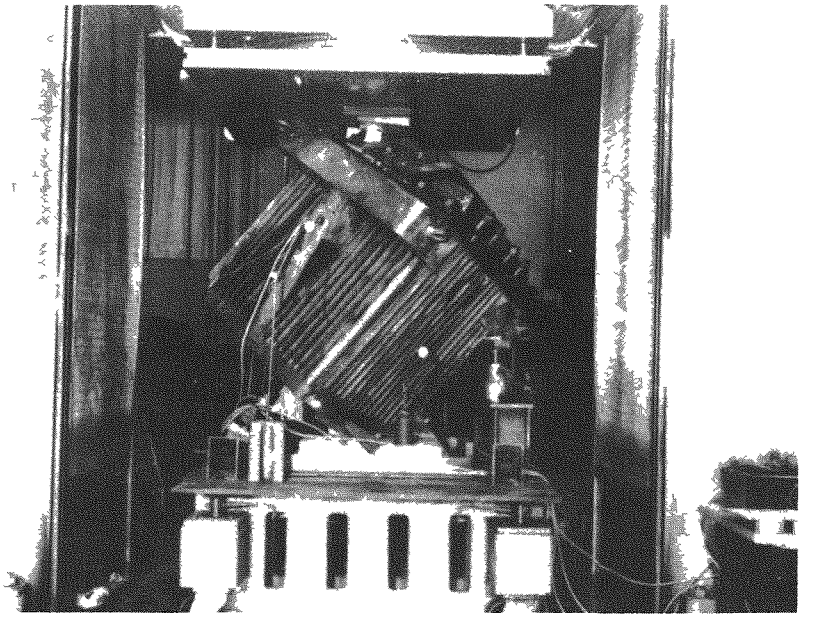


Figure 9 Test No. 8

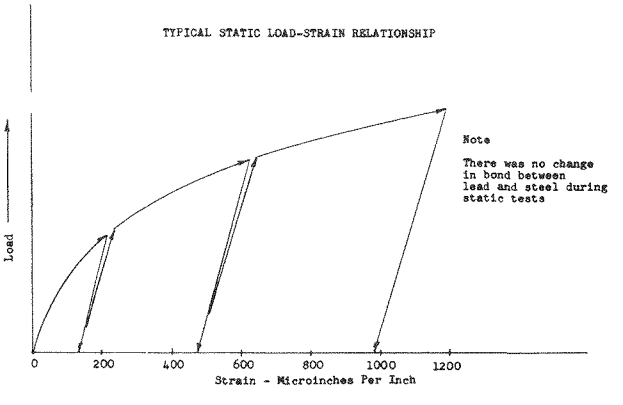


Figure 10

Typical Static Load-Strain Relationship

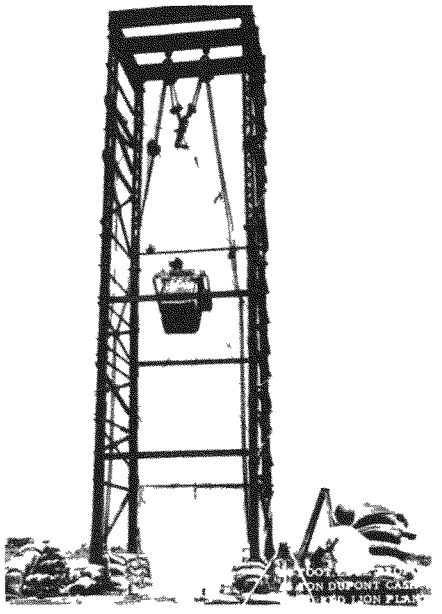


Figure 11 Drop Tower

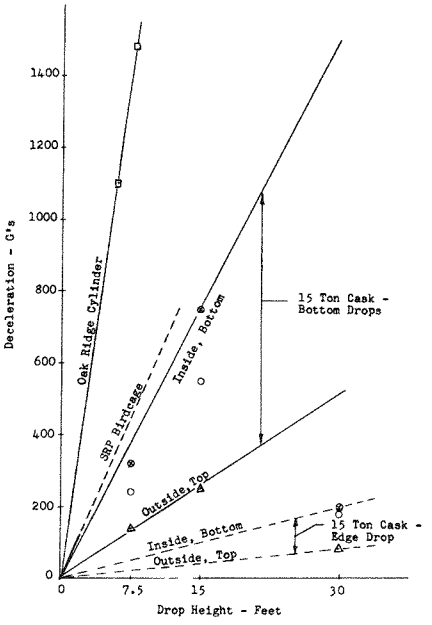


Figure 12

Comparison of Decelerations Recorded in Drop Tests

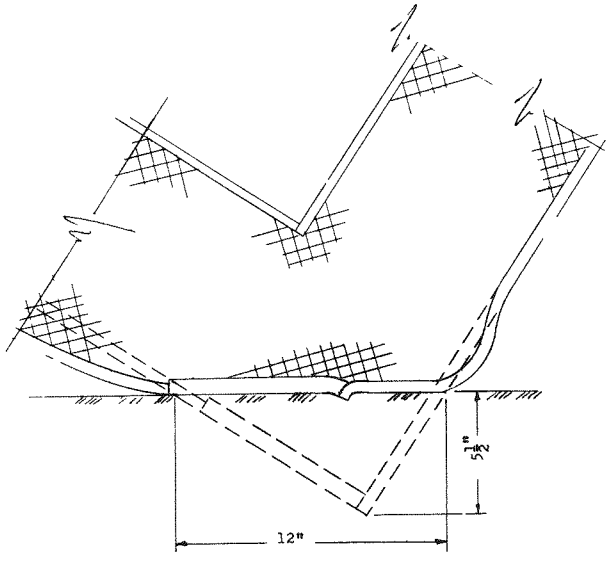


Figure 13

Edge Crushing Caused by 30-Foot Edge Drop

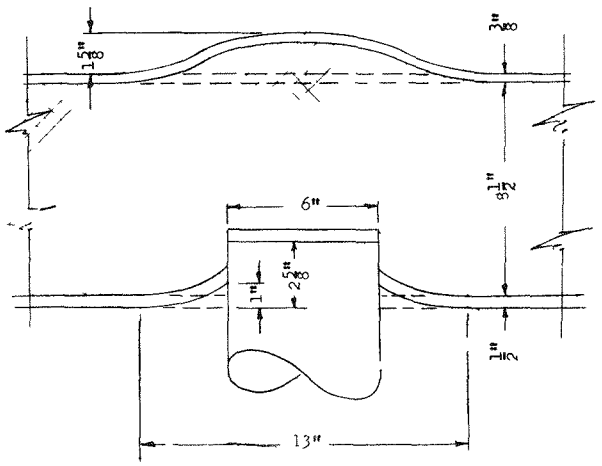


Figure 14

Shaft Penetration Caused by 3-1/2-Foot Drop

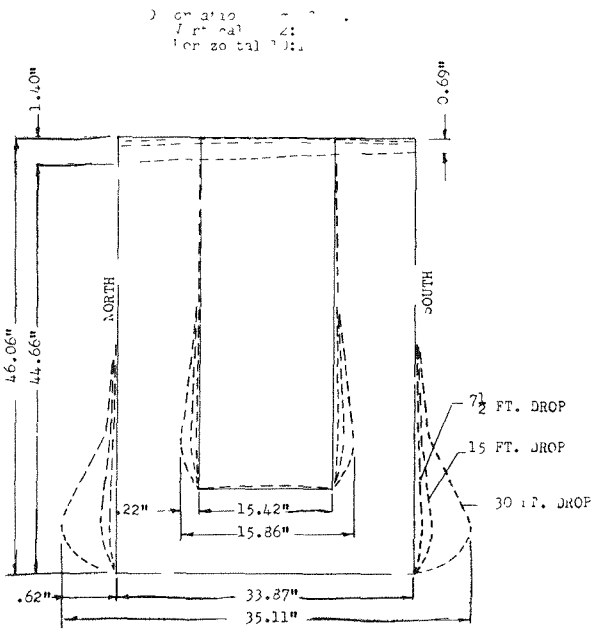


Figure 15

Sectional Elevation Permanent Deformation Due to Bottom Drops

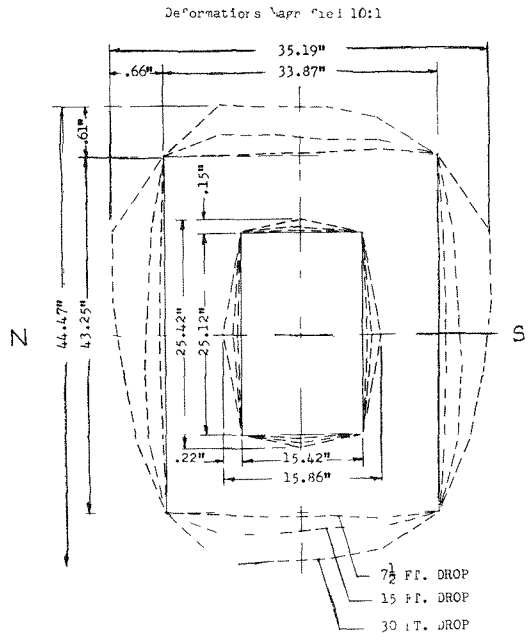


Figure 16

Sectional Plan Permanent Deformation Due to Bottom Drops

D. Static tests indicate the relative resistance of the cask to various loadings, but there appears to be no correlation of strain and deflection at a specific location between static and dynamic tests.

E. Bond between lead and steel is not destroyed by non-destructive static tests or by bottom drops with impact velocities up to 30 mph.

F. Permanent deformations closely resemble those observed on models dropped by the Franklin Institute.

Session Chairman: The next speaker will be Mr. Larry Shappert, Oak Ridge National Laboratory.

THE CASK TESTING PROGRAM AT THE OAK RIDGE NATIONAL LABORATORY

L. B. Shappert

Chemical Technology Division Oak Ridge National Laboratory

INTRODUCTION

Over the past several years, the AEC has been trying to formulate a series of regulations covering the shipment of spent reactor fuel elements. The regulations are to have a dual objective: first, to ensure that such shipments are as safe as possible, and, second, to make the regulations as practical as possible, consistent with safety. There are four main areas of concern with regard to the shipping casks: shielding, criticality, heat transfer and structural integrity. Normally, the first two can be handled without difficulty. The last two points require more careful consideration. This paper deals mainly with our attempt to determine how safe unbuffered, lead-filled shipping casks are with respect to structural integrity.

There are three accident conditions proposed in the regulation which the cask must be capable of withstanding structurally: that of striking an unyielding surface, being impailed, and being involved in a fire. Since the results of accidents are difficult to foresee, the AEC has specified[1] that a cask must withstand the effects of a 15-ft free fall on a solid, unyielding surface. This provides an impact velocity of about 20 mph. Although accidents may occur in which the impact will be at a higher velocity, the key word in the regulation is "unyielding" surface. Since anything the cask hits will undoubtedly yield to some extent, this specification is actually equivalent to a more severe case.

EXPERIMENTAL WORK

Because of the difficulties and lack of data involved in analytically describing the impact of a cask upon some surface, we planned

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[1] Code of Federal Regulations, Title 10, Part 72 (proposed).

and executed an experimental program. In order to implement it, seven cylindrical lead-filled casks were built. Five were 18 in. OD, 10 in. ID, 36 in. long with an outer steel shell thickness of 0.312 in. and weighed about 1.4 tons. The other two casks were 30 in. OD, 18 in. ID, 60 in. long, and weighed about 6 tons. One of the larger casks had an outside shell thickness of 0.500 in. and the other, a shell thickness of 0.375 in. A total of 41 drops were made with the seven casks.

Brittle Lacquer as a Visual Strain Indicator

In order to place strain gages at the points of highest stress, it was necessary to determine such points under impact conditions. This was accomplished by coating two 1.4-ton casks (casks 4 and 5) with a brittle lacquer and dropping them in a horizontal attitude onto a steel plate from heights ranging from 6 in. to 4 ft.[2] Typical results are shown in Fig. 1.

In this drop, the lacquer cracked at points where the strain in the steel shell exceeded 0.012 in./in. Along the line of impact, the brittle lacquer flaked off completely. The maximum stresses form an orthogonal set with the strain cracking, and are greatest where the cracks are closest together. This information enabled us to place the strain gages on the casks so that maximum strain readings were obtained.

Instrumentation

Strain gages, accelerometers, and compressometers comprised the bulk of the instruments on the casks. In addition, inertia switches were used which were supposed to operate at preset g levels to check accelerometer readings but proved unsatisfactory. A schematic picture of the instrumentation is shown in Fig. 2.

A maximum of 12 strain gages were attached to the inside and outside of each cask. They were attached in a standard manner and then covered with a rubber compound for waterproofing.

Two piezoelectric accelerometers were placed either inside or outside of the cask in such a position that their axes were perpendicular to the plane of impact.

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[2]Work done under subcontract with the University of Tennessee.

UNCLASSIFIED
PHOTO 56903

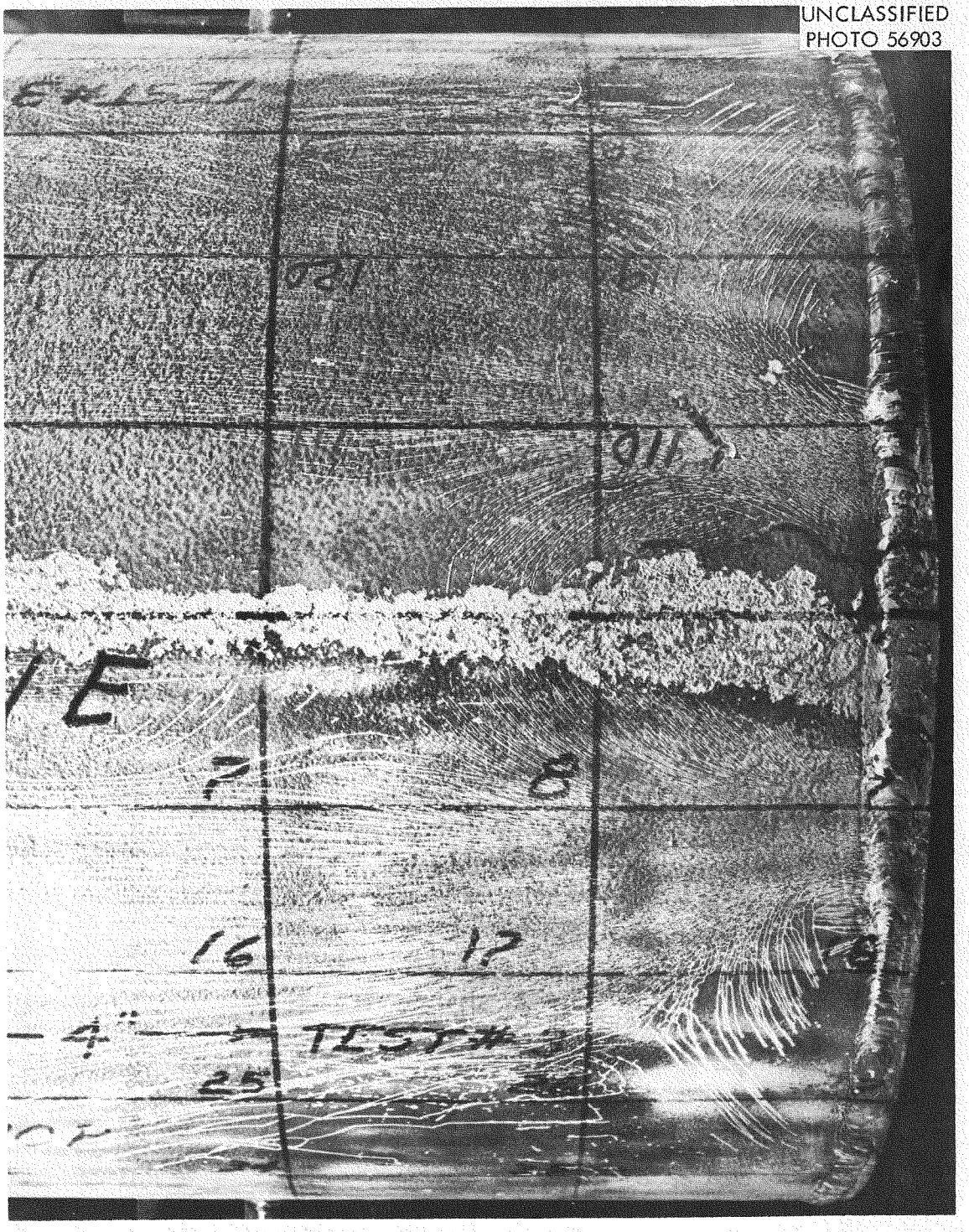
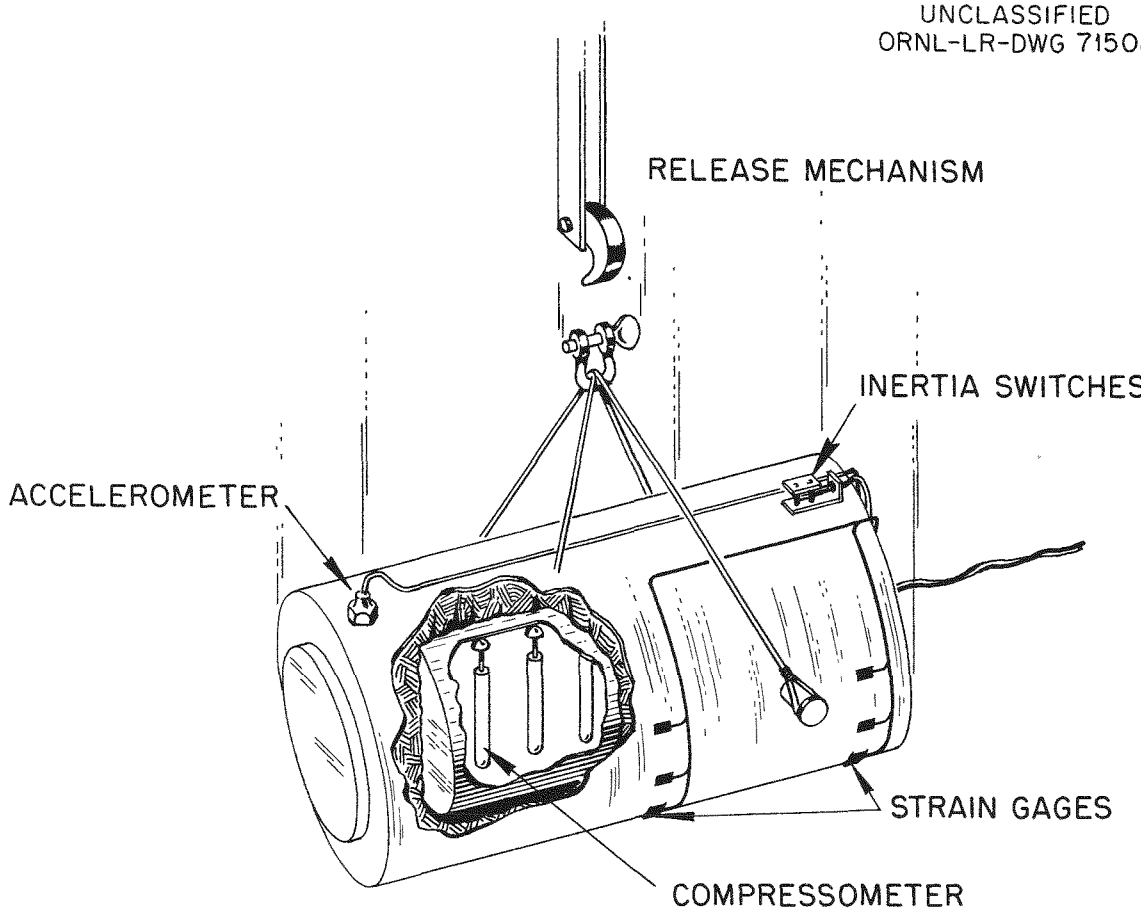


Fig. 1. Stress Cracks in Lacquered 1.4 Ton Cask.



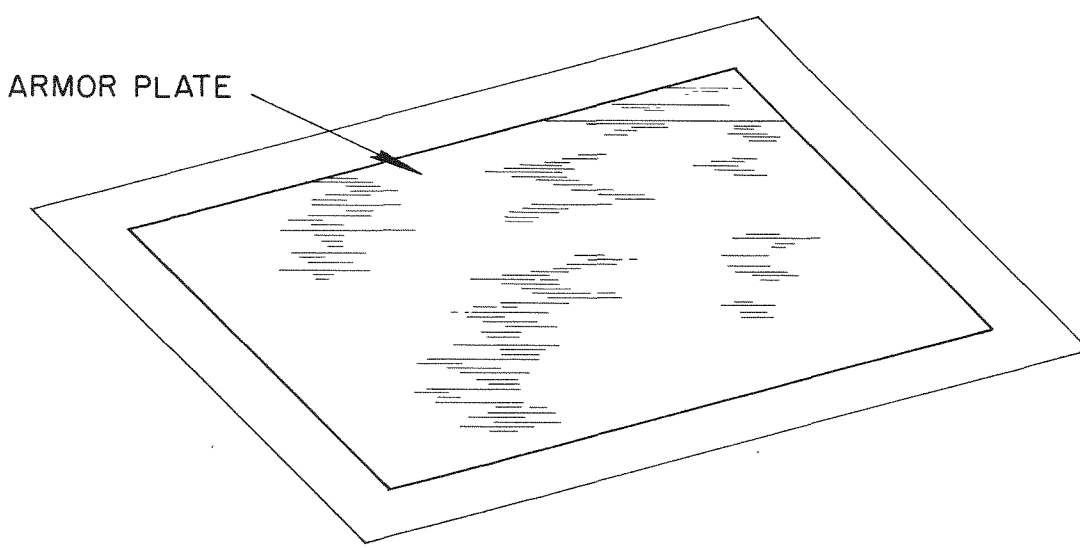


Fig. 2. Cask Instrumentation.

These instruments were wired to a Minneapolis-Honeywell Visicorder, which was able to record 24 channels of information at one time. The Visicorder had a maximum chart speed of 80 in./sec.

In addition to this electronic equipment, compressometers were inserted in the cask cavity to measure the maximum deflection of the vertical internal diameter of the cask cavity at the time of impact. Since the vertical diameter of the cavity was measured before and after the drops, the permanent deflection could be calculated.

In order to provide a positive indication of the cask impact and bounces, the output of a microphone (tapped into the impact surface) was also recorded.

For this set of experiments, failure of a cask was defined as the failure of the steel shell to an extent that the lead could leak out if the cask were exposed to a fire.

Preliminary Drop Tests

After casks 4 and 5 were instrumented (subsequent to the tests described above in which brittle lacquer was used to determine visually the direction of maximum strain), they were dropped from heights ranging from 6 to 16 ft onto a temporary drop pad built from a piece of steel 6 in. thick resting on I beams imbedded in the ground. In all the preliminary drops, none of the steel shells failed. The casks were dropped both in a horizontal attitude and on end.

Permanent Drop Pad

For the final series of tests, a permanent drop pad was built at ORNL and is shown in Fig. 3. It consisted of a 6-ft square of a 4-1/2-in.-thick armor plate backed up by a 12-ft square of reinforced concrete 5 ft thick. The pad rested on a 3-ft-diameter reinforced concrete column reaching down 7 ft to bedrock.

Final Drop Tests

The final cask drops were carried out over a 6-month period and included tests 13 through 41. The majority of these tests were conducted with the cask dropped in a horizontal attitude. The remaining tests were conducted with the cask dropped on a corner at an angle of 45° from the horizontal or with the cask dropped onto a rigid piston (see Appendix I for a complete list of all tests).

Horizontal Drops

Empty 1.4-ton casks were dropped in a horizontal attitude from heights up to 30 ft. In two cases, drops 15 and 29, the cask cavities were 3/4-filled with water. Observations of these results are as follows:

Casks dropped in a horizontal attitude showed a particular tendency to produce a high concentration of stresses around the end plates. This may be

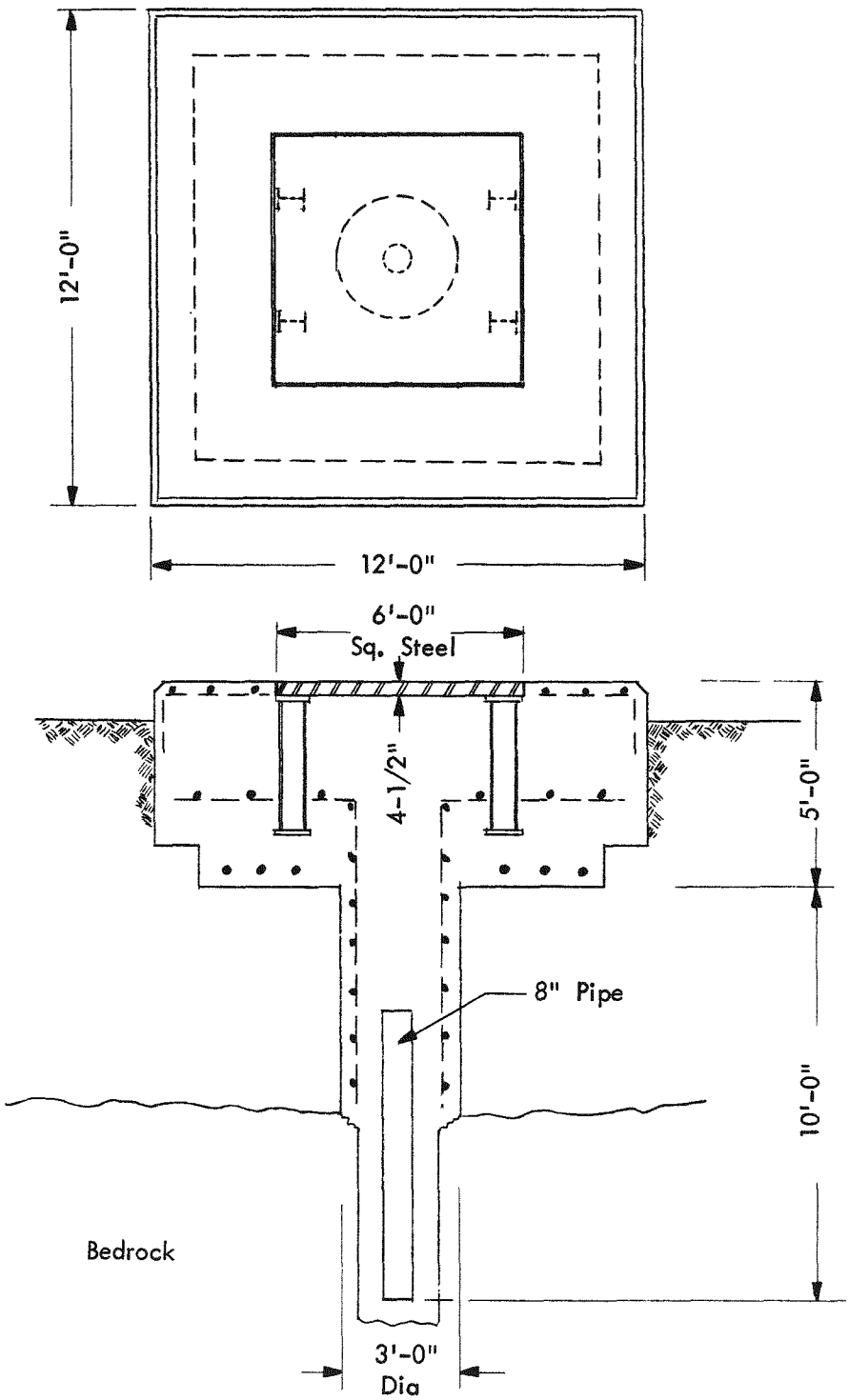


Fig. 3. ORNL Cask Drop Pad.

noted in Fig. 4, where the brittle lacquer flaked off along the line where the outer shell was welded to the end plate.

The only failure observed in a horizontal drop was in the end weld area of a cask dropped from a height of 28 ft. This cask is shown in Fig. 5. It should be pointed out, however, that no welding specifications were used in making these casks, and, in some cases, only about a third of the available area was welded. In addition, due to the necessity of having to drop each cask more than once, this cask had previously been dropped from a height of 15 ft on the same side and 23 ft on the opposite side. The failure may be noted in the weld directly at the point of impact and around the plug used to seal the filler hole in the cask.

In the two horizontal drops in which the cavity was 3/4 filled with water (drops 15 and 29), the first was a drop from a height of 15 ft. The cask did not leak after the drop in spite of the fact that several bolts which held the end cover plates on were sheared off. The second test, however, in which the cask was dropped from 23 ft did leak after the drop.

An interesting aspect of the water-filled cask drops is that higher strains are noted than in comparable positions on dry casks dropped from the same height. This observation is reinforced by the fact that the change in the vertical internal diameter is greater with water present.

The rigidity of the casks dropped in the horizontal attitude is improved by the end plates and closures on the cask. This becomes obvious from studying deformation measurements of the vertical diameter as noted in Table 1 for the 1.4-ton casks. In drop 6, the cask did not hit perfectly flat, which accounts for the large maximum deformation at one end.

Recorded strains vary from point to point on the surface of the cask. An output chart for drop 25 is shown in Appendix 2. The vertical time lines are 0.01 sec apart. Note that peak strains and decelerations are both reached in 3 to 5 milliseconds. Results of strain measurements from several drops are shown in Table 2. A positive number indicates tension, and a negative number indicates compression.

As would be expected, the largest strains are in the cask cavity directly over the point of impact. To some extent, the cask behaves as a rigid cylinder, as described by Roark.[3] The sense of the strains are, in general, as he predicts.

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[3]Roark, R. J., Formulas for Stress and Strain, McGraw-Hill Book Co., Inc., New York, 1954, Edition 3, p. 299.

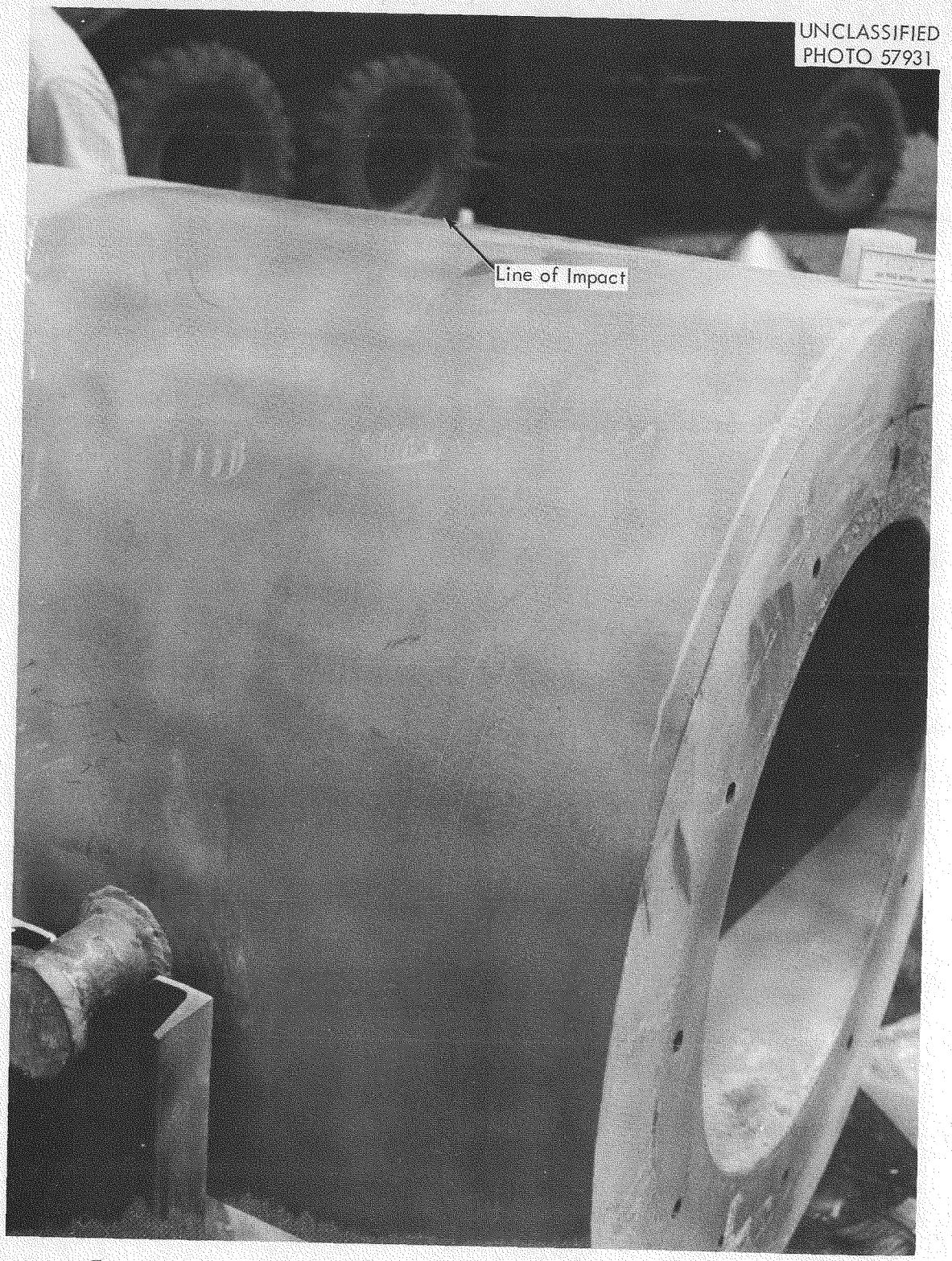


Fig. 4. Stress Concentration in Circumferential Weld -6-Ton Cask.

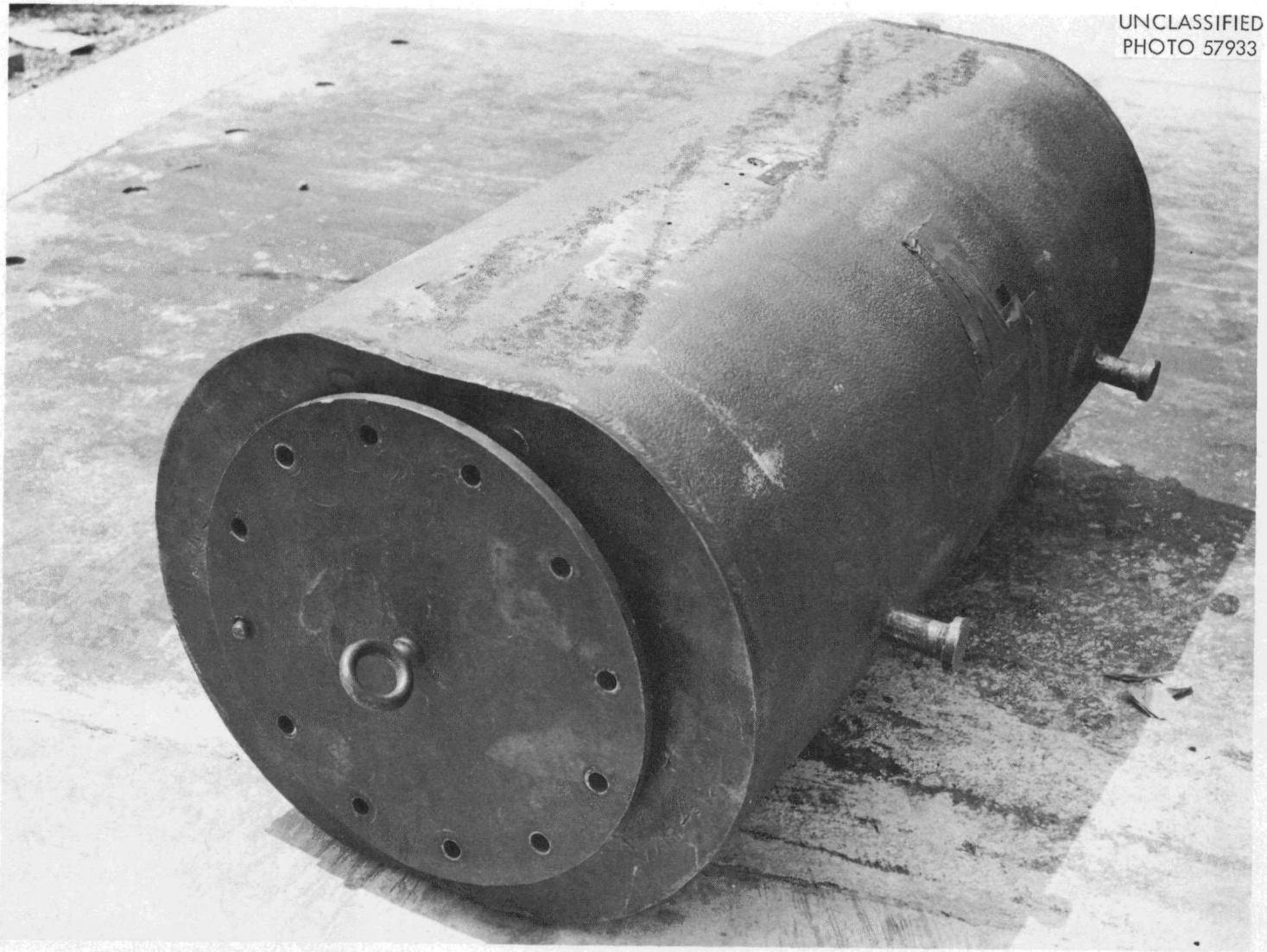
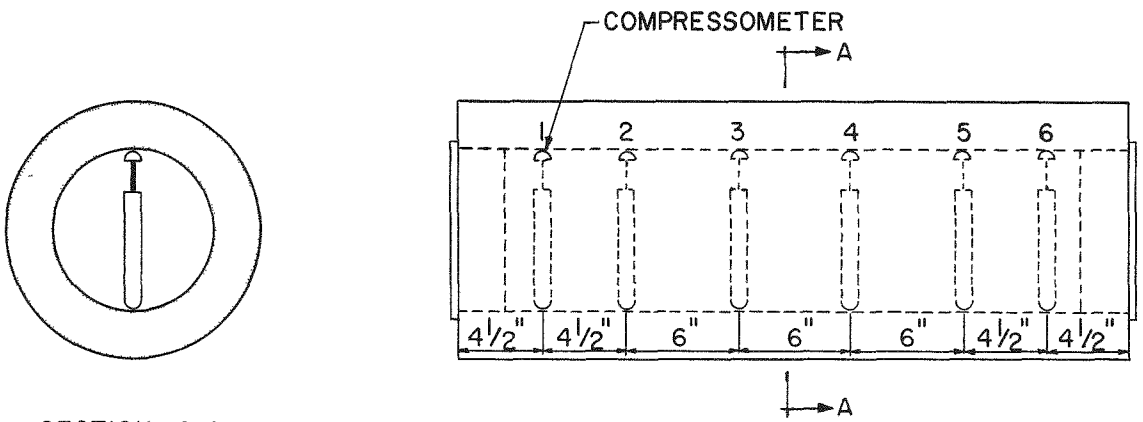


Fig. 5. Results of 15- and 28-ft Drop - 1.4 Ton Cask.

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SECTION A-A

COMPRESSOMETER POSITIONS

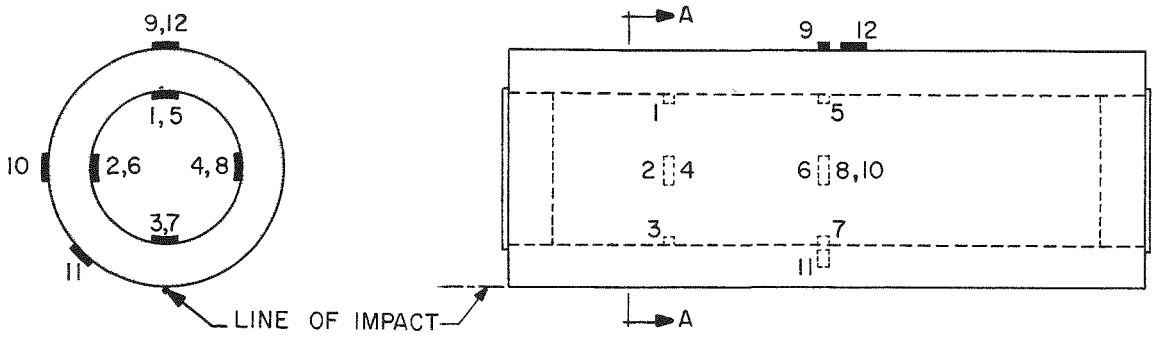
FIG. 6

TABLE 1

Cavity Deformation in Horizontal Drops, 1.4-Ton Cask

Drop		Maximum Deformation, in.						Permanent Deformation, in.					
No.	Height (ft)	1	2	3	4	5	6	1	2	3	4	5	6
6	6	.161	.126	.132	.118	.105	.047	.050	.061	.099	.073	.062	.011
7	8	.130	.158	.173	.160	.123	.104	.053	.058	.059	.059	.047	.029
8	12	.109	.096	.131	.168	.185	.164	.045	.046	.057	.075	.094	.090
9	16	.128	.187	.233		.244	.188	.082	.108	.136	.139	.146	.121

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SECTION A-A

STRAIN GAGE POSITIONS

FIG. 7

TABLE 2

Strain Readings in Horizontal Drops

Drop No.	1	2	3	4	5	6	7	8	9	10	11	12
					Maximum Strain, micro in./in.							
19	424	-1795	-444	-1071	886	-648	7076	-1645	1165	-	-	588
24	-	-	-	-	1203	-1962	4468	-1694	653	491	-	-
25	3409	-915	6070	-1669	-	-2273	-	-3109	1865	647	-	-152
26	402	-691	5294	-161	1120	-1417	-	-1274	1422	580	-	-
29	632	-963	7750	-990	-	-3006	-	-2758	1785	523	2628	-764
					Residual Strain, micro in./in.							
19	181	384	-	-202	485	-222	7018	-1006	957	-	-	-
24	-	-	-	-	625	-1110	4329	-1103	201	177	-	-
25	4349	-603	5965	-1240	-	-1717	-	-2547	904	446	-	-271
26	73	-279	5183	-121	620	-647	-	-442	491	149		
29	382	-692	7651	-636		-2657	-	-2381	1384	351	2559	-275

Corner Drops

All corner drops were made with the cask at a 45° angle to the impact surface. Due to rigging problems, the center of gravity was not directly over the point of impact.

Figure 8 shows a sequenced photograph of a 1.4-ton cask dropped on its corner from a height of 15 ft. Note that approximately 1/2 sec elapsed from the time of impact until the cask came to rest. The results of this drop may be seen in Figs. 9 and 10.

The cask was again coated with a brittle lacquer. Radial strain lines at the periphery of the cask were produced on the end where the first impact occurred and may be clearly seen in Fig. 9 (stress lines occur in a perpendicular direction to the strain lines). This contrasts with the circumferential strains noted on the opposite end of the cask, which were also produced as a result of the first impact (see Fig. 10). The second impact, which occurred at the opposite end of the cask, produced radial strains which were superimposed on the original circumferential drains. This is also visible in Fig. 10. These effects were probably caused by the inertia of the inside shell of the cask at the time of impact.

Also note in Fig. 9 the two unstressed "disks" in the cover plate (on opposite sides of the center hole) with a high concentration of stresses around them. In Fig. 10, two similar unstressed "disks" may be noted outside the cover plate in the end plate at a 45° angle from the vertical. These disks define the holes through which the lead was poured into the cover plate and into the annular space of the shield and which were subsequently closed with a welded steel disk.

In the 15-ft drop, a slight, barely visible crack in the weld area at the point of impact was noted. However, a 23-ft corner drop produced a crack 4 in. long and 1/4 in. wide in the weld area where the end plate joins the outer shall, easily visible in Fig. 11.

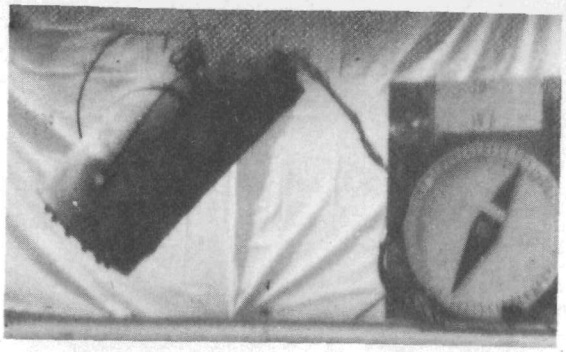
Corner drops of the 6-ton cask, in general, gave results similar to those found by dropping the 1.4-ton casks, except that somewhat bigger weld cracks were produced from identical drop heights.

Table 3 presents a measurement of the permanent deformations of the cask cavity in the vertical plane resulting from a corner drop from 15 ft.

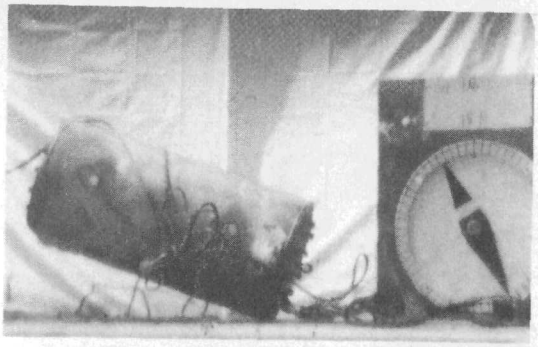
Table 3. Cavity Deformation of a Corner Drop

Drop No.	Height, ft	Permanent deformation, (in.)[a] 1	2	3	4	5	6
16	15	0.070	0.080	0.057	0.046	0.041	0.067

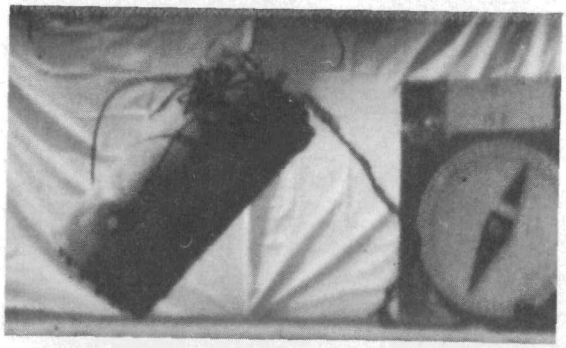
[a]Measured at original compressometer positions as given in Table 1.



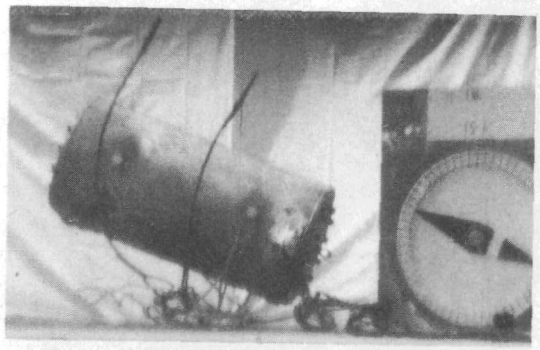
Prior to impact



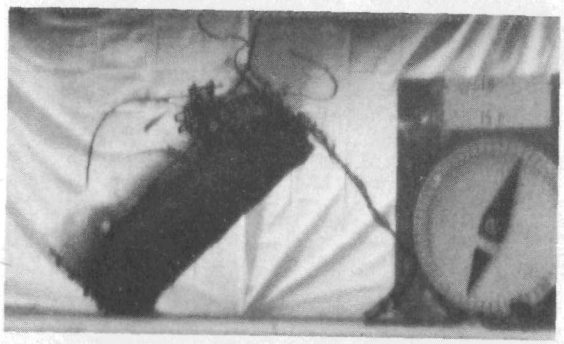
Second impact - time: 0.102 sec



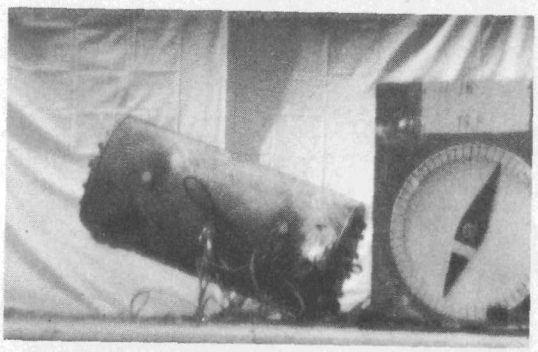
Initial impact - time: 0.000 sec



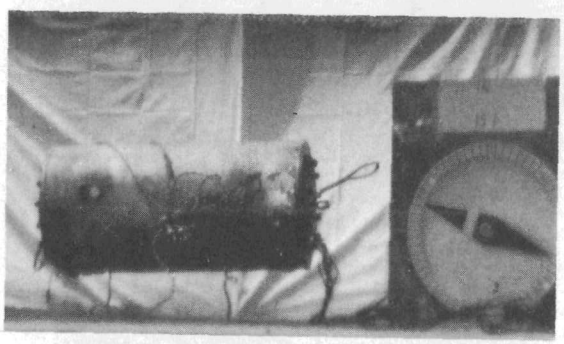
Second bounce - time: 0.196 sec



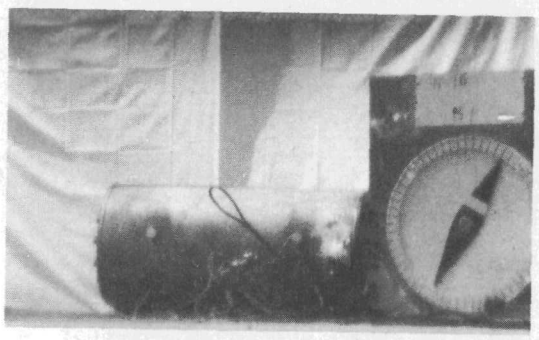
Peak deceleration - time: 0.0083 sec



Third impact - time: 0.391 sec



First bounce - time: 0.071 sec



Final position - time: 0.515 sec

Fig. 8. Corner Drop of a 1.4 Ton Model Shipping Cask, Drop Height 15 ft.

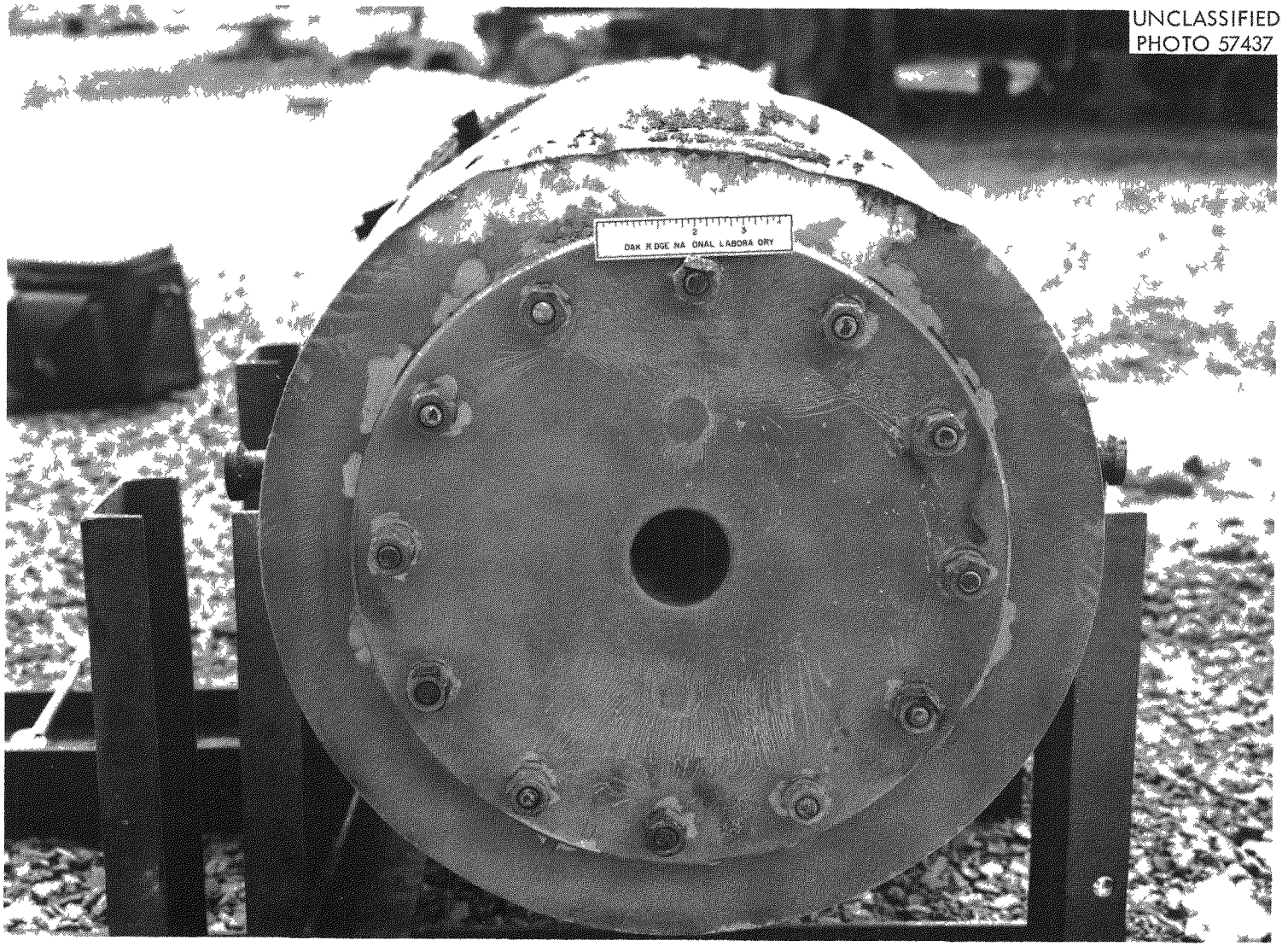


Fig. 9. Results of 15-ft Corner Drop - 1.4-Ton Cask.

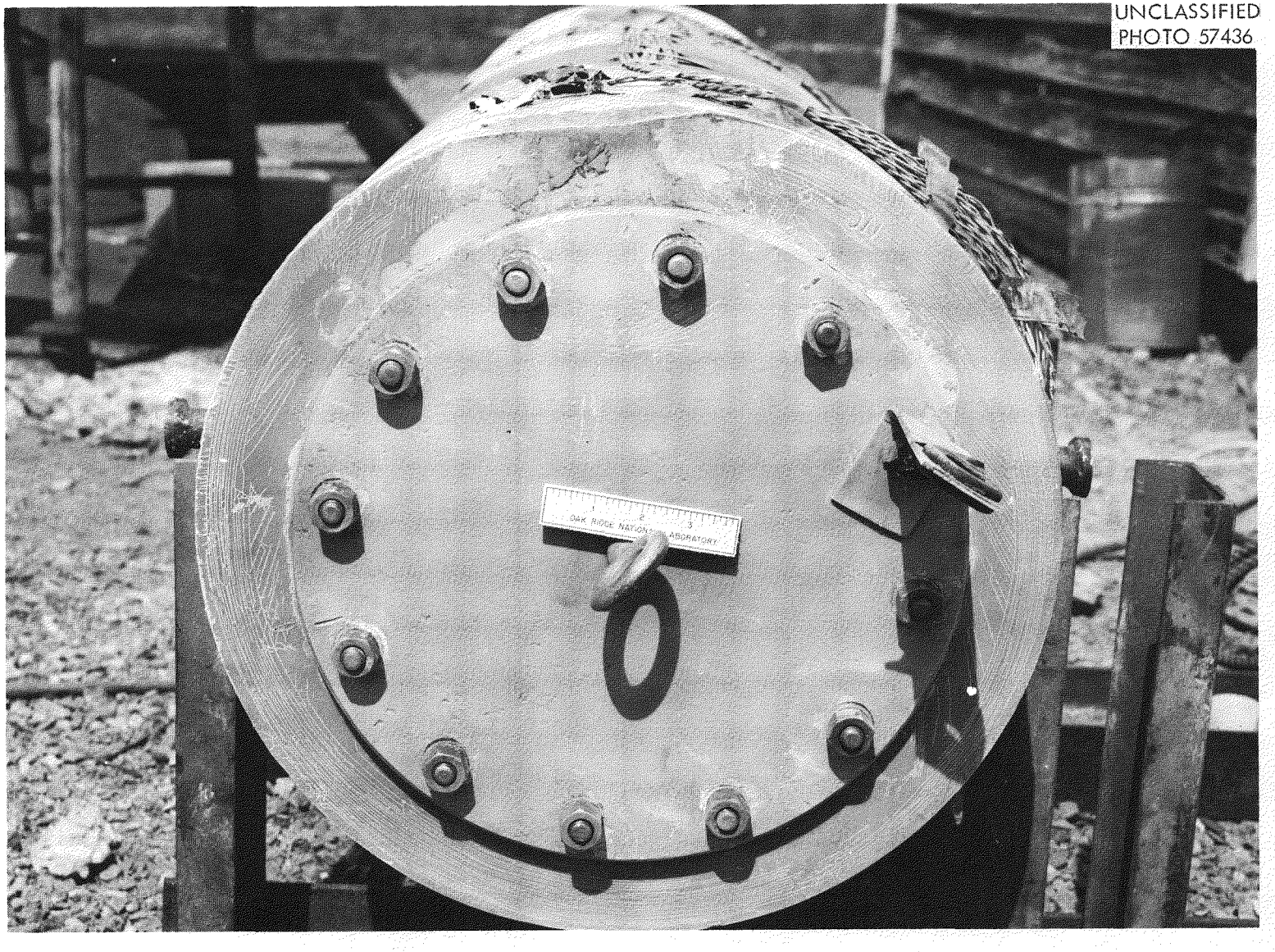


Fig. 10. Results of 15-ft Corner Drop - 1.4-Ton Cask.

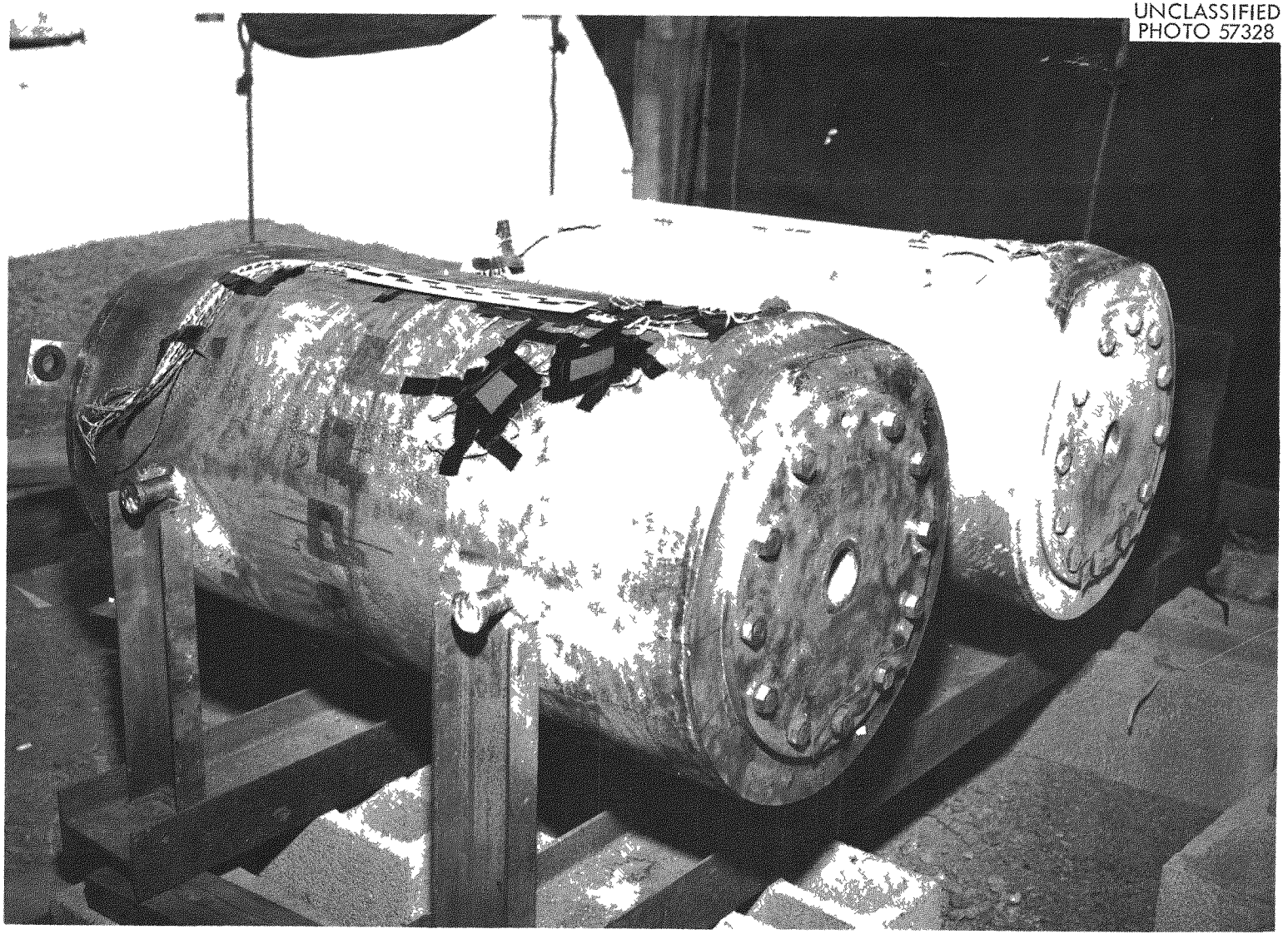


Fig. 11. Results of 23- and 15-ft Corner Drop - 1.4-Ton Casks.

Piston Drops

The 1.4-ton cask was first tested in this manner by dropping it in a horizontal attitude onto a 6-in.-diam piston from a height of 3.5 ft. In this test, the piston did not penetrate the outer shell. In later drop tests, a 2-in.-diam piston was used. The change was made because the cask can be considered a model of roughly 1/3 the size of an actual cask, and the AEC regulations stipulate a 6-in.-diam piston for the full sized cask.

In subsequent experiments, it became evident that the penetration results were strongly affected by the surface condition of the piston. A slightly rounded head, caused by a number of previous drops, would not shear through the outer shell as easily as a flat, sharp-cornered piston. All results are from drops onto flat-headed pistons.

The 2-in.-diam piston sheared through the outer shell of the 1.4-ton cask and penetrated into the lead when dropped from heights above 2 ft. At a drop height of 6.5 ft, the piston penetrated into the lead and dimpled the inner steel shell. The results of a 3.5-ft drop is shown in Fig. 12. The 6-ton casks were dropped onto a 4-in.-diam piston from drop heights of 3.5 and 5 ft. Both impacts penetrated the outer shell. Table 4 presents the results of all important piston tests.

Table 4. Results of Piston Tests

Cask Weight (tons)	Approximate lead thickness (in.)	Drop Height (ft)	Penetration into lead[a] (in.)
1.4	4	2.0	1/8
	4	3.5	7/8
	4	5.0	1-1/2
	4	6.5	2-1/4
6.0	6	3.5	1-7/8
	6	5.0	3-1/4

[a]Measured from resulting cask surface. There is, in addition, a dimple roughly 1/2 in. in depth in 1.4-ton casks and roughly 1 in. in the 6-ton casks.

Energy Absorption

In order to better understand the behavior of casks under impact conditions, it is desirable to know how the energy is dissipated. To this end, an energy balance equation was written describing how the energy is absorbed by the cask. The equation is as follows:

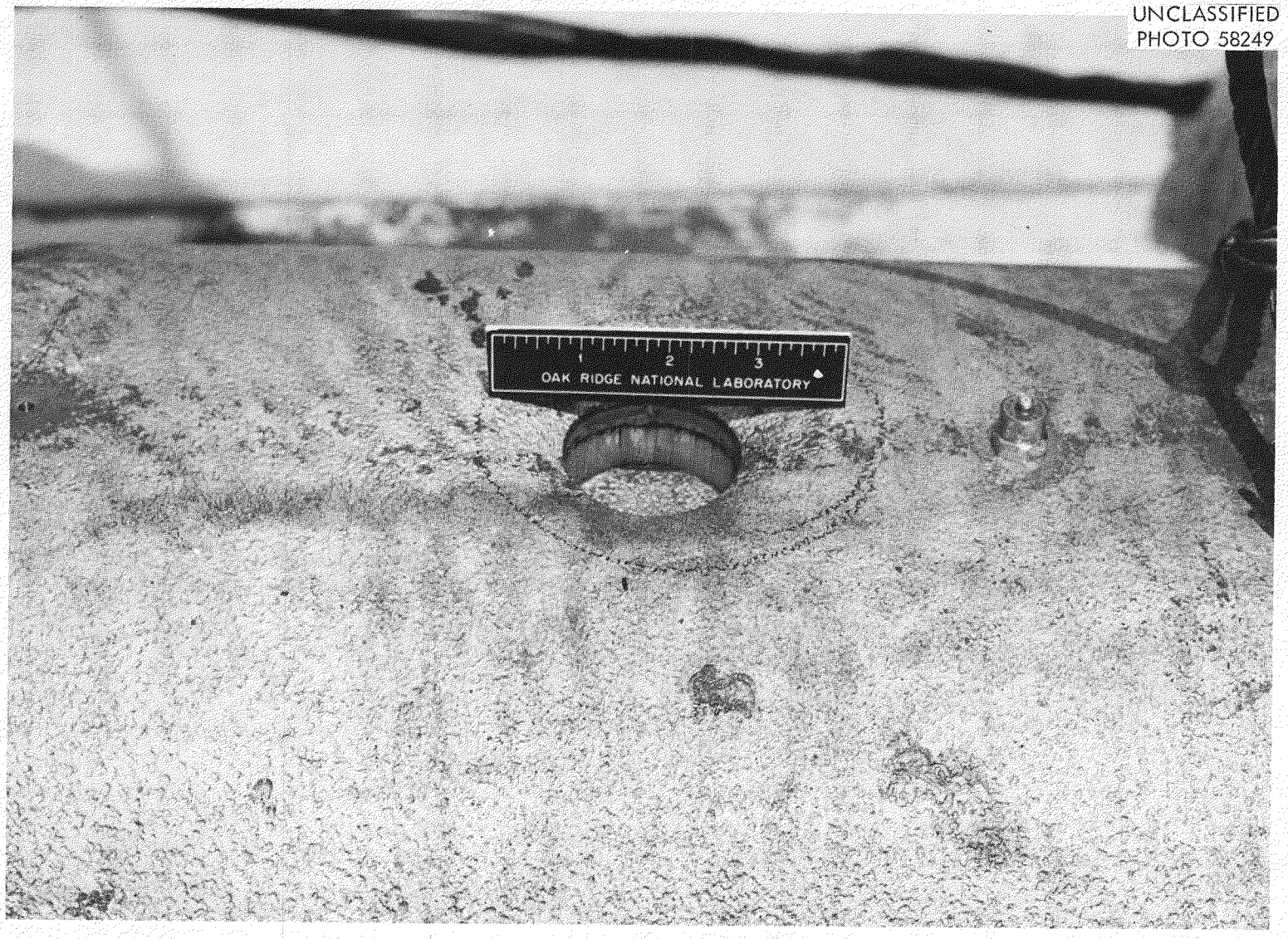


Fig. 12. Results of 3.5-ft Drop on 2-in. Diam Piston.

$$E_t = E_{Pb} + E_s + E_b + E_f,$$

where

E_t is the total energy available in the drop,

E_{Pb} is the energy absorbed in the lead,

E_s is the energy absorbed in shearing the outer shell in a piston drop,

E_b is the energy absorbed in bending the steel shells, and,

E_f is the energy dissipated in friction.

The left side of the equation is equal to the weight of the cask times the drop height. The right-hand members are more difficult to accurately evaluate, however, preliminary results of such an approach appear encouraging.

RESULTS

Keeping in mind the limitations previously described, the results may best be summarized as follows:

1. Weld failure was noted on corner drops above 15 ft for both the 1.4- and 6-ton cask. Welds were, in general, poor.

2. The only weld failure that occurred in horizontal drops was found on a 1.4-ton cask dropped 28 ft. The cask had previously been dropped 15 ft on the same side.

3. End drops caused little visual damage to 1.4-ton casks below drop heights of 16 ft.

4. Circumferential welds of the end plate to the outer shell receive high concentration of stresses under impact conditions.

5. Higher stresses are recorded on the inside shell than in a comparable location on the outside shell except at the area of impact.

6. High stresses are found at discontinuities such as lead fill hole plugs. Care must be taken in welding such holes.

7. For the same drop heights, larger stresses and greater deformations are noted in casks which are water filled (compare drops 19 and 29).

8. Two-in.-diam pistons will penetrate the outer shell of a 1.4-ton cask at drop heights above 2 ft.

9. The duration of the initial impact of a 1.4- and 6-ton cask dropped in a horizontal attitude is, in general, less than 10 milliseconds, and the maximum number of g's is reached in less than 5 milliseconds.

CONCLUSIONS

It appears that a steel-shelled lead-filled cask should have little difficulty in meeting the AEC normal-impact requirements. However, it seems that it would be quite difficult for such a cask to meet the puncture test applied with a 6-in.-diam piston without including shock-absorbing structures. It should be remembered that it does not take a large amount of energy to shear through steel plate such as might be presented by a cask shell.

Under the circumstances, it might be well to consider another test which is probably more representative of an actual accident than pure puncturing type of impact. Such a test has been proposed by the British[4] and consists of dropping a cask on a 1-ft-wide beam which has a maximum deflection of 0.01 in. under a static 50-ton load. This impact test is severe and realistic, and it could probably be more easily met by lead-filled casks than the puncture test.

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[4] Messenger, W. and Fairbarin, A., "The Transportation of Radioactive Materials. Interim Proposals for the Application of Environmental Tests to the Approval of Packaging," Appendix O, Test Specification No. 41 (Draft).

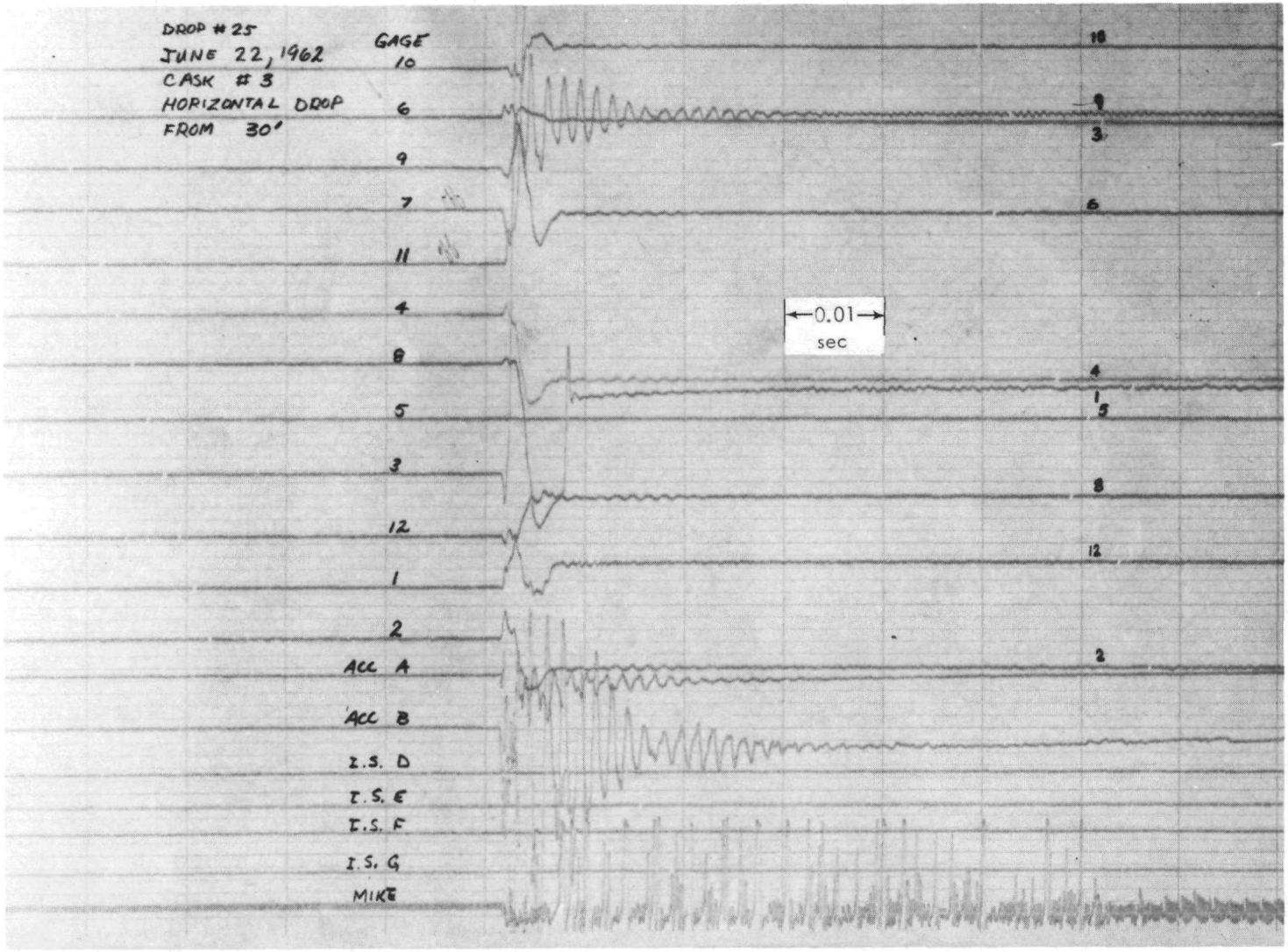
APPENDIX 1

CASK DROP TESTS

Drop No.	Type	Height	Cask No.	Nominal Cask Wt, Tons	Comments
1-5	Horizontal	1/2 to 4'	4&5	1.4	Coated with brittle lacquer
6	Horizontal	6'	4	1.4	No failure
7	Horizontal	8'	5	1.4	No failure
8	Horizontal	12'	4	1.4	No failure
9	Horizontal	16'	5	1.4	No failure
10	Vertical	10'	4	1.4	No visual damage to shells
11	Vertical	16'	4	1.4	No visual damage to shells
12	Vertical	16'	5	1.4	No visual damage to shells
13	Angle-45°	15'	4	1.4	Failure in weld at point of impact
14	Angle-45°	23'	5	1.4	Failure in weld at point of impact
15	Horizontal	15'	1	1.4	Water filled
16	Angle	15'	2	1.4	Coated with brittle lacquer
17	Horizontal	15'	3	1.4	No failure
18	Horizontal, piston	3.5'	2	1.4	6" diam - dented, no puncture
19	Horizontal	23'	3	1.4	No failure
20	Horizontal	2'	L1	6.0	Coated with brittle lacquer
21	Horizontal, trunions	10'	5	1.4	Seal welds around trunions broke
22	Horizontal, piston	5'	2	1.4	6" diam - dented, no puncture
23	Horizontal, trunion	20'	5	1.4	Seal welds broke
24	Horizontal	4'	L1	6.0	Coated with brittle lacquer
25	Horizontal	28'	3	1.4	Failure in weld - slight dimple in inner shell
26	Horizontal	8'	L2	6.0	No failure

APPENDIX 1

Drop No.	Type	Height	Cask No.	Nominal Cask Wt, Tons	Comments
27	Horizontal, piston	5'	5	1.4	2" diameter piston
28	Horizontal, piston	5'	5	1.4	2" diameter piston
29	Horizontal	23'	1	1.4	Water filled - all water lost
30	Horizontal	12'	L1	6.0	No failure
31	Horizontal	20'	L2	6.0	A very poor weld broke
32	2 in. piston	1'	4	1.4	In 32-35, the piston did not puncture the cask, probably because it was blunted by previous drops
33	2 in. piston	2.5'	4	1.4	
34	2 in. piston	3.0'	3	1.4	
35	2 in. piston	4.0'	3	1.4	No data taken
36	Horizontal	25'	L1	6.0	
37	4 in. piston	3.5'	L2	6.0	
38	2 in. piston	6.5'	5	1.4	Same cask as 32-35, unblunted piston caused puncture at 2 ft drop height
39	2 in. piston	2.0'		1.4	
40	Corner drop	15'	L1	6.0	
41	4 in. piston	5'	L2	6.0	


DROP # 25
JUNE 22, 1962
CASK # 3
HORIZONTAL DROP
FROM 30'
GAGE
10
6
9
7
11
4
8
5
3
12
1
2
ACC A
ACC B
I.S. D
I.S. E
I.S. F
I.S. G
MIKE
0.01
sec
10
9
3
6
4
1
5
8
12
2

APPENDIX 2

Remarks by Mr. Shappert: Since our object was to determine whether or not we can predict the effect of cask impact, we attempted to determine where the energy went on these drops and we did this by trying to develop an energy balance around the cask.

To this end, the energy balance equation was written describing how the energy is absorbed by the cask.

The energy absorbed in the lead was determined from the volume of lead displaced. Measuring the total depth on the puncture test and, for the horizontal drop, measuring the flat made by the impact, an estimate was made of the volume of lead that was actually pushed out of the way.

Some results of a 2 1/2, two, 3 1/2, five and six-foot drop for the 1.4-ton cask were reported. The total energy available is the drop height times the cask weight. The energy that was absorbed by the lead, is a function of the volume of lead displaced and that could be measured. The energy absorbed in shear for the two-inch diameter piston was the same in all cases.

I couldn't think of any way to determine the energy absorption of bending and friction except by differences. Interestingly enough, the energy absorption by bending and friction for the first three drop tests came out very similar which was encouraging in such an experimental program as this.

The fourth difference came out to be roughly three times the others. This can be explained from the fact that it is the highest drop height, 6-1/2 feet, and actually penetrated far enough to dimple the inner shell. This means that more work was done in bending and friction in the last drop than probably was done in the previous three drops. For comparison I used some figures that John Langhaar and Harry Clarke furnished me about the piston drop of the 15-ton cask. Using these measurements the total energy absorbed in bending and friction came out about what you would expect based on the data on these smaller casks.

The results of the energy absorption of the horizontal drops were not nearly as good as the piston drops. This points up the fact that there was more energy absorbed in bending and friction of the steel in the horizontal drops than there is in the piston drops. This is pretty much as you would expect because of the localized affect of the piston whereas the horizontal drop produces an affect across the whole length of the cask.

A plot of the percent of energy absorbed in the lead on these drops show a trend at least. The higher the drop height the less, percent-wise, is the amount of energy absorbed in lead for the horizontal drop, more of the energy being absorbed in the steel. Conversely with piston drops the higher the drop height, the more of the energy will be absorbed in the lead.

We are hoping to establish how much energy is actually absorbed in the steel rather than to get it by differences.

As a result of most of these drops the casks took slightly permanent sets in the internal shell and of course the external shell deformed in almost every case. Except for the actual impact area, the inner shell was subjected to higher stresses than comparable positions on the outside shell of the cask.

The change of internal diameter of these casks under most impact conditions was in the tenths of an inch. However, in the very high drop heights, from 20 to 30 feet, we actually got deformations of the internal diameter up to one inch.

In no drop, including the piston drop, end drop, corner drop, or side drop, was the inner cavity ever violated. That is, it was never punctured. In one of the drops we actually got it to leak water. We dropped two casks that were filled with water. One was dropped 15 feet which did not leak; one dropped from 23 feet did leak around the gaskets, but the inner cavity was never violated.

In conclusion, there will be apparently little difficulty in meeting these 15-foot free-fall requirements if the cask is dropped normal to any side. There is some doubt whether the outer shell can withstand 30 times the weight of the cask delivered by a six-inch diamter piston without including a shock-absorbing structure around the outside of the shell. We feel, however, we can estimate the results of these horizontal or piston drops with a reasonable degree of accuracy based on an energy balance around the cask.

I think we should consider whether a piston test is really necessary, desirable or reasonable for lead-filled casks. I suggest we consider it in the light of some of the tests and consider the British proposal of drop tests on a beam with specified amount of deformation. In some ways, this type of drop is more severe than the piston drop and in some cases less severe.

DISCUSSION AND COMMENTS

The homogeneous bonding of lead to steel is a concept used for good heat transfer media. Not all cask designers or fabricators use this concept. There are other concepts which some people believe provide a better heat transfer medium than homogeneous lead and steel bonding.

Mr. Thisell stated that there is evidence that the bond between lead and steel is important in the action of the plastic action of the lead absorbing the energy of the impact.

Mr. Shappert indicated there was no homogeneous bonding between the lead and the steel in the cask dropped. Hence, there is evidence that the results might be the same regardless of homogeneous bonding of the lead and the steel.

Mr. Thisell indicated the only evidence was in the shape of the stress deformation curve. The continuously plastic action that was observed which caused the steel to act in a plastic manner, because they were actually measuring the strain in the steel itself, indicated that there was a bond which existed between the lead and the steel which prevented the steel from acting in an elastic manner and that therefore this bond was important in the over-all action of the cask. Perhaps further tests should be carried out to confirm or deny that fact.

There are 40 casks now existing which are or will shortly transport irradiated fuel which are cylindrical casks and in which the lead and steel are not homogeneously bonded but other heat transfer methods are used, not including mechanical equipment. Since this represents a substantial proportion of casks, it was suggested that the testing program include what happens in casks where the lead and steel are not homogeneously bonded.

With the container empty, one would expect that the internal cavity would deflect inwardly on impact. It didn't. Of course, the outer shell was subjected to an internal pressure which caused it to deflect outwardly as you would expect. But the outer shell is less stiff than the inner shell due to the length factor. Therefore it was more easily moved, i.e., deflected or deformed. In some deforming there was sufficient bond between the outer shell, the lead, and the inner shell to pull the inner shell along with it.

It is also possible that the deflection in the internal bottom plate could develop enough that the bottom edge of the internal cavity plate would be deflected upward. This deflection was significant even in the bottom drops.

(UK comment) - Regarding the beam test proposed in the UKAEA, we looked at the 10 CFR 72 six-inch puncture test and found it rather frightening. We regard the drop test on the 12" wide beam as a sort of compromise between the puncture test and dropping the cask onto a flat surface.

The primary object of the tests just reported were to see if the casks will be safe in an accident. If you look at 10 CFR 72, it indicates a number of tests. However, no individual one of these tests should be regarded in itself as representing a maximum credible accident. It certainly represents a very severe accident but not a maximum credible accident. As I think I said earlier, we have taken the view that the maximum credible accident that is generally appropriate is represented by a very severe impact followed by fire, and possibly in some circumstances by immersion in water or the effect of a high pressure fire hose. It seems to me if you are going to make these drop tests, they cannot be looked at in isolation. If you drop a flask and its integrity remains, you still have not proved whether it will stand the accident. If the welds crack, it does not really matter, provided you are not going to have a fire. It seems to me it is a question of what is the combined effect of the impact plus fire. I don't think there is difficulty in keeping the lid on these casks. I don't think that is a point very much in dispute. I just leave that as a question.

We are groping for our criteria which will tend to lead us into the direction of proper design. A test of an isolated situation is not nearly as valuable as the testing of a system.

It was suggested that when ORNL started out with the cask testing program, the results were uncertain. It wasn't known whether the tests that were proposed were unduly severe. It seems that there probably will not be any problem with the lid staying on. As a matter of fact, in some of the six-ton casks ORNL found it very difficult to get the lid off after they were dropped.

In one or two cases five sticks of dynamite were detonated inside the casks and they didn't open up.

The deceleration figures reported in the Philadelphia tests appear a great deal higher than the 30 to 60 G's referred to in Mr. Langhaar's paper yesterday.

In this regard, it was noted that a structure may be subjected to an extremely large load without danger of failure if the duration of the load is sufficiently short. This seems to be a function of the natural period of the structure among other things. The regulations call for the 60 G's to be applied for a minimum of 16 milliseconds. In the DuPont test, this load was approximately 2 to 3000ths of a second, a very short duration. Although the strain recorded perhaps reached a peak in about 5000ths of a second.

On the problem of deceleration, the number of G's, it is obvious that if a particle comes in contact with an unyielding surface and the particle is moving at some high velocity, if it is stopped in zero time, it suffers an infinite rate of deceleration.

As was mentioned a little while ago, various parts of a cask structure will decelerate at different rates. We understand the Canadian authorities are thinking in terms of maybe 500 G's as deceleration.

We must think about what we mean when we say the cask is subjected to some deceleration force or some rate of deceleration. 10 CFR 72 talks about 30 G's and 60 G's, but does not refer to any particular part of the cask.

In the drop of the 15-ton cask, 300 G's was measured in the inside of the cask in a 7-1/2-foot drop. At the same time, a point at the top of the cask decelerated somewhere in the neighborhood of 300 G's. On the 15-foot drop, the inside bottom of the cask which was separated from the armor plate by only two sheets of steel and some lead, measured a deceleration of around 700 G's.

Also, the unyielding surface did yield to the extent of a half-inch or more. These low number of G's, 320, 700, were probably due to the deflection of our unyielding surface. It can be accounted for entirely by that deflection. If we had a truly unyielding surface, the figures would have been probably 10,000 G's or more. So the concept of the number of G's in designing casks is probably not a very good concept.

It usually is considered that the weakest part should withstand an impact of that order specified.

There is some confusion about how to interpret the number of G's and how to interpret the deceleration force. Perhaps the impact from a given height which is described in energy rather than an impulse is a method of describing the problem which is subject to some sort of experimental work.

The problem associated with the use of the G value is that it depends on what part of the cask we are talking about. In the back of the paper from the Oak Ridge National Laboratory is a trace of the dynamic stresses in one of the casks that has been dropped. The time measured is in the range of five milliseconds and not the 16 milliseconds described in the regulations.

Session Chairman: The next paper is by Mr. Clarke of the Franklin Institute of Philadelphia.

MODEL IMPACT TESTS PERTAINING TO SHIPPING CONTAINERS FOR RADIOACTIVE MATERIALS

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Research on shipping containers for radioactive materials is being conducted at The Franklin Institute with the objective of developing quantitative methods for assessing the structural integrity of such containers during both normal transport operations and accidents. This is a broad objective and requires consideration not only of containers themselves but also of vehicles, rigging and the overall shipping environment. In other words one must determine both the conditions imposed on casks during shipment and their response to these conditions. A major part of this problem involves the behavior of casks when subjected to various kinds of impacts each severe enough to perhaps cause permanent deformation or even rupture of some part of the cask structure. The use of models was anticipated to be an economical way in which to approach the problem. Hence, a model testing program was undertaken to accomplish the dual purpose of (1) developing experimentally verified methods for analyzing and predicting the response of casks to impacts, and (2) providing quantitative data on material and structural behavior which can be used with the analytical methods to design casks having known impact resistance. With such data and methods one could design casks that will be strong enough to withstand most transportation accidents and yet economical to construct and ship.

Before a model testing program was undertaken the techniques of dimensional analysis were employed to find and examine relations which could exist among the physical quantities believed sufficient to define the impact behavior of containers. This study showed that if a model and prototype cask were geometrically similar, made of identical materials, and subjected to the same impact velocity, they would experience equal strains unless the stress-strain relations of the materials were dependent upon the rate at which the materials were deformed. This latter point had to be investigated before a model testing program could be undertaken with any assurance of success, since the technical literature contains many examples of materials whose strength is indeed dependent on the rate of deformation. Consequently, a series of impact tests was performed with spherical specimens made of chemical lead, a

major constituent of most shipping containers in use in this country. Several spheres that were dropped from different heights onto a heavy steel block are shown in Figure 1. The deformed areas are flat and obviously increase in size with increasing drop height and specimen size. Figure 2 reveals that the strain is proportional to impact velocity and, more importantly, does not vary more that $\pm 5\%$ over the 9 to 1 range of sphere size. Thus any size effect that might be attributed to rate of deformation of the lead is small enough to be neglected for the present in model test studies. A few tests were also made in which lead rods were subjected to tensile impact loads. These rods elongated considerably with "necking" near the impacted end as illustrated in Figure 3. Qualitatively, the results indicate no appreciable size effect; precise quantitative data on stains throughout these rods has not been obtained because effects from both stress waves and structural inhomogeneity were evidently present and could not be separated.

A number of impact tests have been performed on small model casks for the purpose of finding how modes of deformation might be affected by factors such as cask shape, impact attitude and velocity, closure, and the presence of liquid in the inner cavity. It was hoped that the loading conditions of greatest severity in terms of damage produced could be identified, so that these conditions would subsequently be studied more exhaustively. Data from the tests was also expected to be of use in developing analytical methods for describing and predicting the impact damage. The model casks were cylindrical and cubical, shapes common to actual containers in current use. They were made small in size (30 lb. and 5 in. on a side) and with few details in order to achieve economy and ease in fabrication and testing. They are not scale models of specific casks but do have typical proportions and are constructed from chemical lead and mild steel joined by welding. Several of these casks that have been subjected to impacts at velocities of about 30 mph are shown in Figures 4, 5 and 6. These casks show that impacts on edges and corners cause extensive permanent deformation (more so than impacts over a side or end). Rupture of the outer shell occurred only for impacts on the cover of the cubic casks; these are apprently more vulnerable than the cylindric ones. In general, the cover impacts indicate the desirability of protecting the cover from direct exposure to impact forces. Further, the closure region should contain extra material distributed in such a manner as to make its strength more nearly equal to that of other areas of the cask. In Figure 6 the left hand cask has suffered about the same total deformation (though distributed differently) as the cask on the right in spite of the fact that the weld at the top is much heavier. This illustrates the point that strengthening one part of a cask exposed to impact may merely shift the damage elsewhere without increasing its overall impact resistance appreciably. The results of dropping a cask onto a cylindrical pin from heights of 3.5 and 11 ft. are shown in Figure 7. Casks with the relatively thin outer shells in common use are evidently quite vulnerable to this kind of an impact.

Most of the larger casks are at temperatures above their surroundings during shipment. In some instances the inner shell may

be at temperatures of 200 to 250°F. The question thus arises whether such temperatures might have a significant effect on the impact behavior of the lead which constitutes the greater part of the cask wall. To investigate this question a series of impact tests of lead spheres at temperatures ranging up to 250°F is being carried out. These tests are not entirely complete, but the results do not appear to show any large effect of temperature on the deformations due to impact.

Undoubtedly the most important aspect of the impact testing of reduced-scale models of containers is that of validity of results. Do these small models really behave during impact like larger models and full size casks? It must be demonstrated conclusively that this is indeed the case in a quantitative as well as a qualitative sense, or the utility of model testing is severely restricted. To investigate this point a series of impact tests with exact scale models has been undertaken. Three more or less typical shapes of cask were selected-cylindrical, cubical and rectangular. The following models are being constructed and tested:

(1) 1/4 scale models of the 1.4 ton cylindrical cask of ORNL.

(2) a 1/8 scale model of the 15 ton cubical slug cask of DuPont (all details included).

(3) 1/10 and 1/4 scale models of the 55 ton rectangular cask of DuPont (major details only included).

Three cylindrical models and one cubical model have been fabricated and the rectangular models are currently under construction. Only the cylindrical models have been tested. These were subjected to impacts on a side and a corner (45° angle) and on cylindrical pins from several drop heights. The particular tests duplicate one performed at ORNL on the larger cask models. Figures 8, 9 and 10 provide pertinent data on the models and show one of them prior to test. Figure 11 reveals the deformation produced at the inpact region by dropping the model on its side from a height of 15 ft. Actual dimensions of the flattened area are given in Figure 12; values that would be predicted for the larger ORNL model are given for comparison purposes. The agreement is very good. The permanent deformations of the inside of the model are tabulated in Figure 13. Again the agreement between the predicted and actual deformations of the larger ORNL model is satisfactory. The damage resulting from a drop of 15 ft. onto a corner of the small-scale cylindrical model is shown in Figures 14, 15 and 16. Data on the deformed region is presented in Figure 17. Predicted values of those items for which acceptable measurements were available on the larger model agree well with the actual values. The damage which resulted from the several penetration tests appears in Figure 18. A drop from 6-1/2 ft. penetrated the wall to a considerable depth, causing the inner wall to bulge appreciably (see Figure 19). Data from the penetration tests are summarized in Figure 20. In this instance the values predicted for the larger ORNL model are significantly lower than those actually observed. The source of this discrepancy is not presently known. Two extra pene-

tration tests were made in a search for the cause. These tests revealed that radius of the edge and hardness of the penetrator both affect the depth to which the wall is penetrated or sheared (Fig. 20). From the results of these tests it is evident that detailed features of the penetrator must be standardized if comparable results are to be obtained by different investigators. Further experimental work and perhaps some analysis are desirable on the penetration problem to explain the observed differences. However, if an explanation can not be found with a reasonable effort, it should still be possible to obtain useful results from model tests by adjusting the drop height used in the model tests to compensate for the model size. Such a correction could readily be obtained from an additional series of penetration tests. Components of the exact scale model that has been constructed of the 15 ton cubical Slug cask are shown in Figure 21. This photograph shows the stiffener gussets at the bottom of the cask and the tinning of the internal surfaces. An exterior view of the completely assembled model is given in Figure 22. The plan is to subject this model to the identical tests that were performed on the full size cask.

The feasibility of model testing as a means for studying the impact behavior of shipping containers may be considered on the following basis:

(1) validity of results when used to predict damage to full size casks.

(2) whether details of a large cask can physically be duplicated in a small model.

(3) cost of fabricating scale models.

The model testing that has been done at both the Franklin Institute and the Oak Ridge National Laboratory demonstrates that a great deal of significant information on the impact behavior of casks can be obtained economically by this means. The detailed exact scale model of the 15 ton Slug cask shown in Figure 22 cost about $1200 to construct; the simplified models are appreciably cheaper. Fabrication costs have been found to range from about $200.00 for simple scale models to about $1500 for exact scale models incorporating nearly all details of the prototype cask.

There is no question but what impact tests of reduced-scale models can reveal in a qualitative sense those configurations, materials and fabrication techniques which increase impact resistance. In other words they point out the ways to achieve stronger and safer casks. More significantly the model test results so far obtained support the conclusion that quantitative predictions of the behavior of a prototype cask can be made from tests of exact scale models. In any actual situation where a container design is particularly critical (exceptionally hazardous contents or unusually severe impact conditions), tests of exact scale models provide a practical economical way to conclusively establish the integrity of the cask. It is hoped that analytical methods can be developed in the near furture to accomplish this same objective.

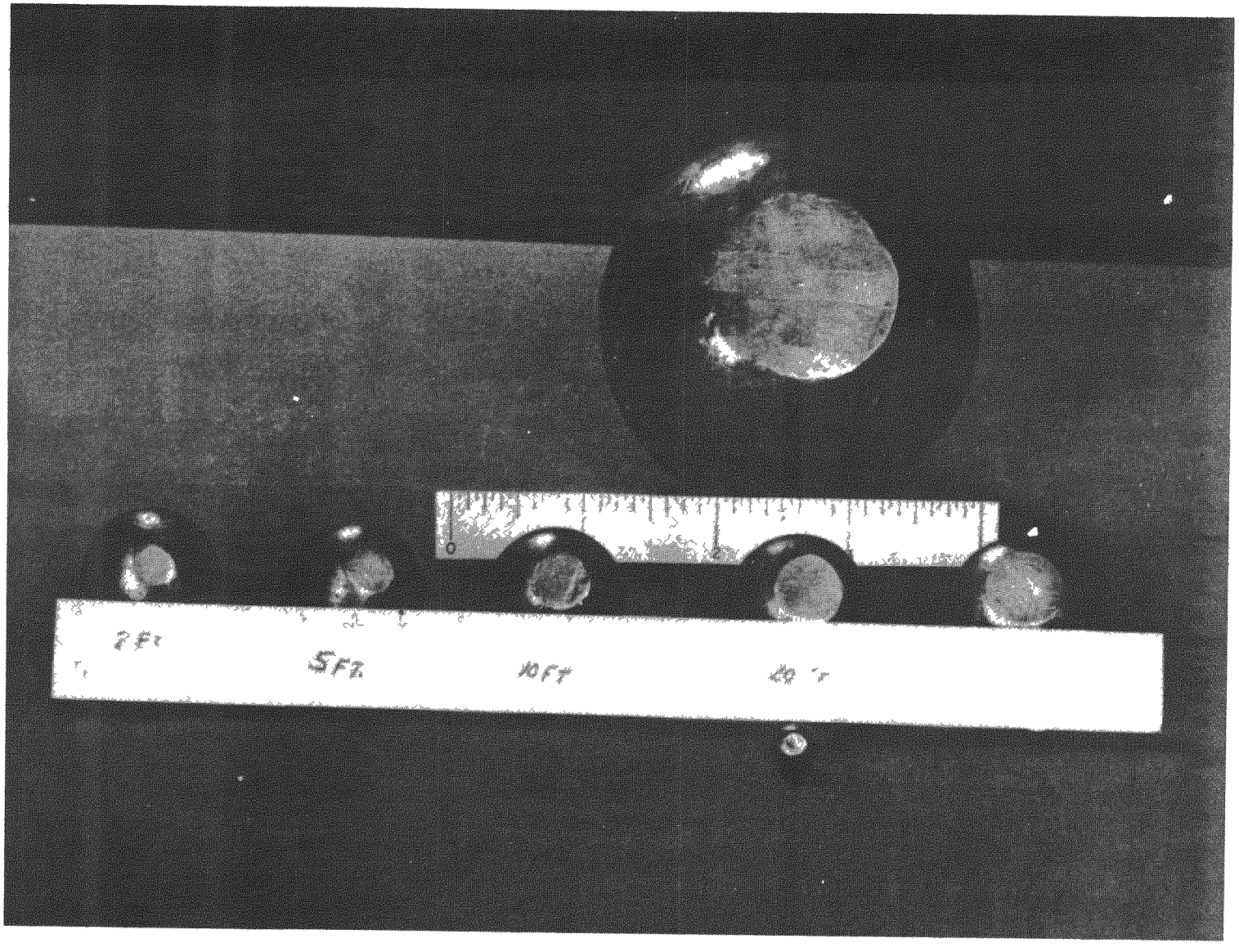


FIG. 1 - LEAD SPHERES AFTER COMPRESSIVE IMPACT

FIG. 2 - IMPACT OF LEAD SPHERES

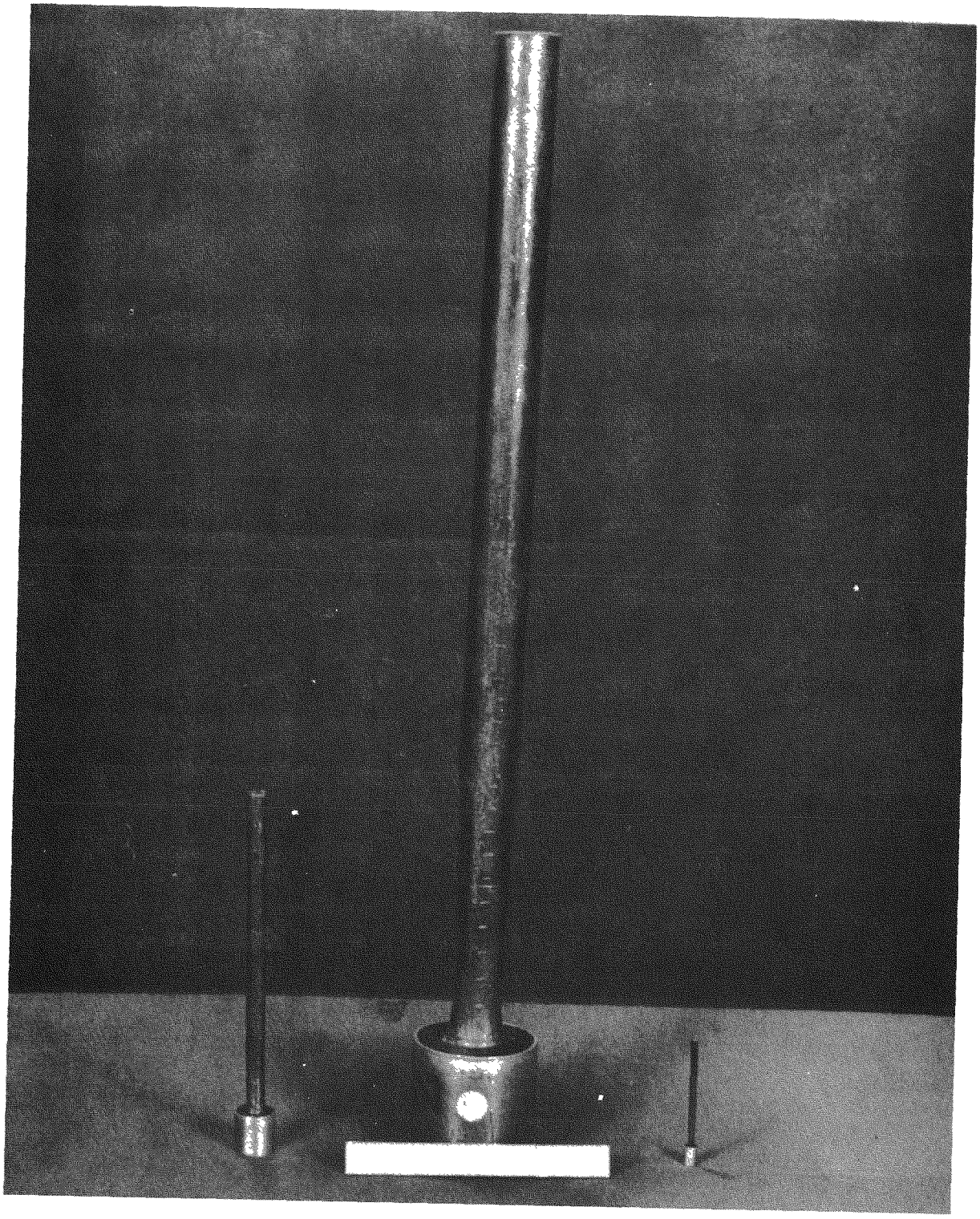


FIG. 3 - LEAD RODS AFTER TENSILE IMPACT

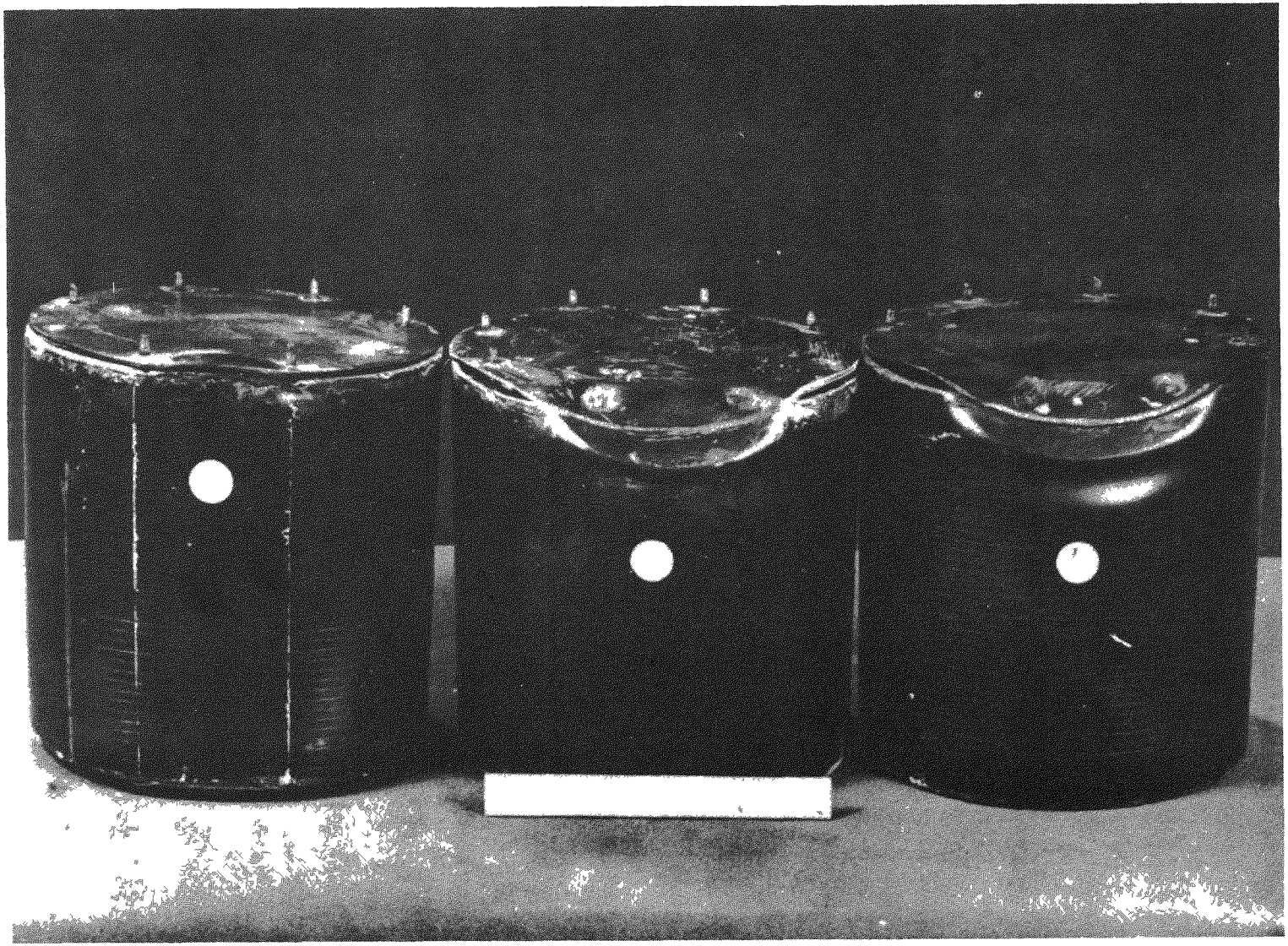


FIG. 4 - IMPACT DAMAGE TO CYLINDRIC MODEL CASKS

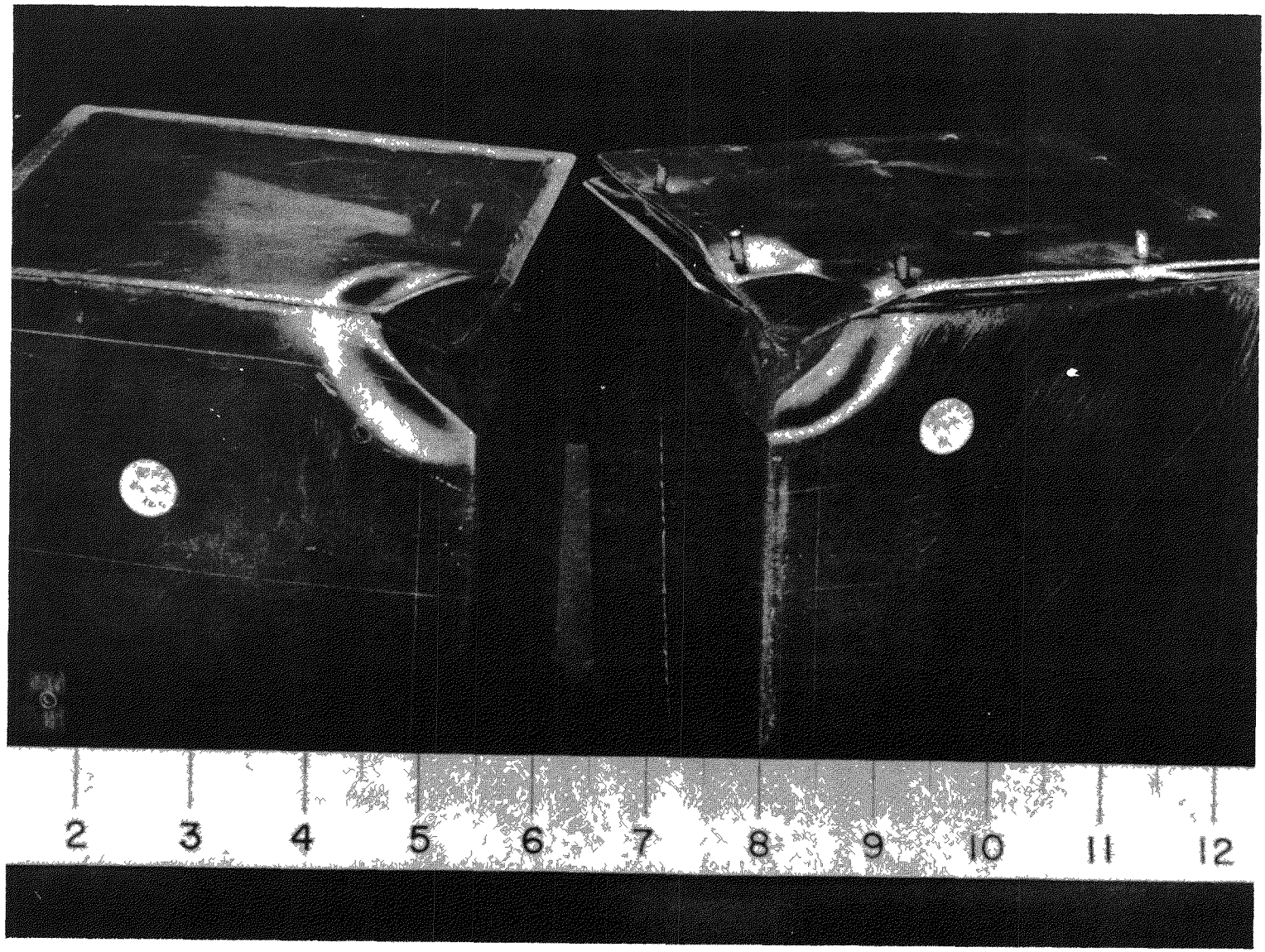


FIG. 5 - CUBIC MODEL CASKS AFTER CORNER IMPACT

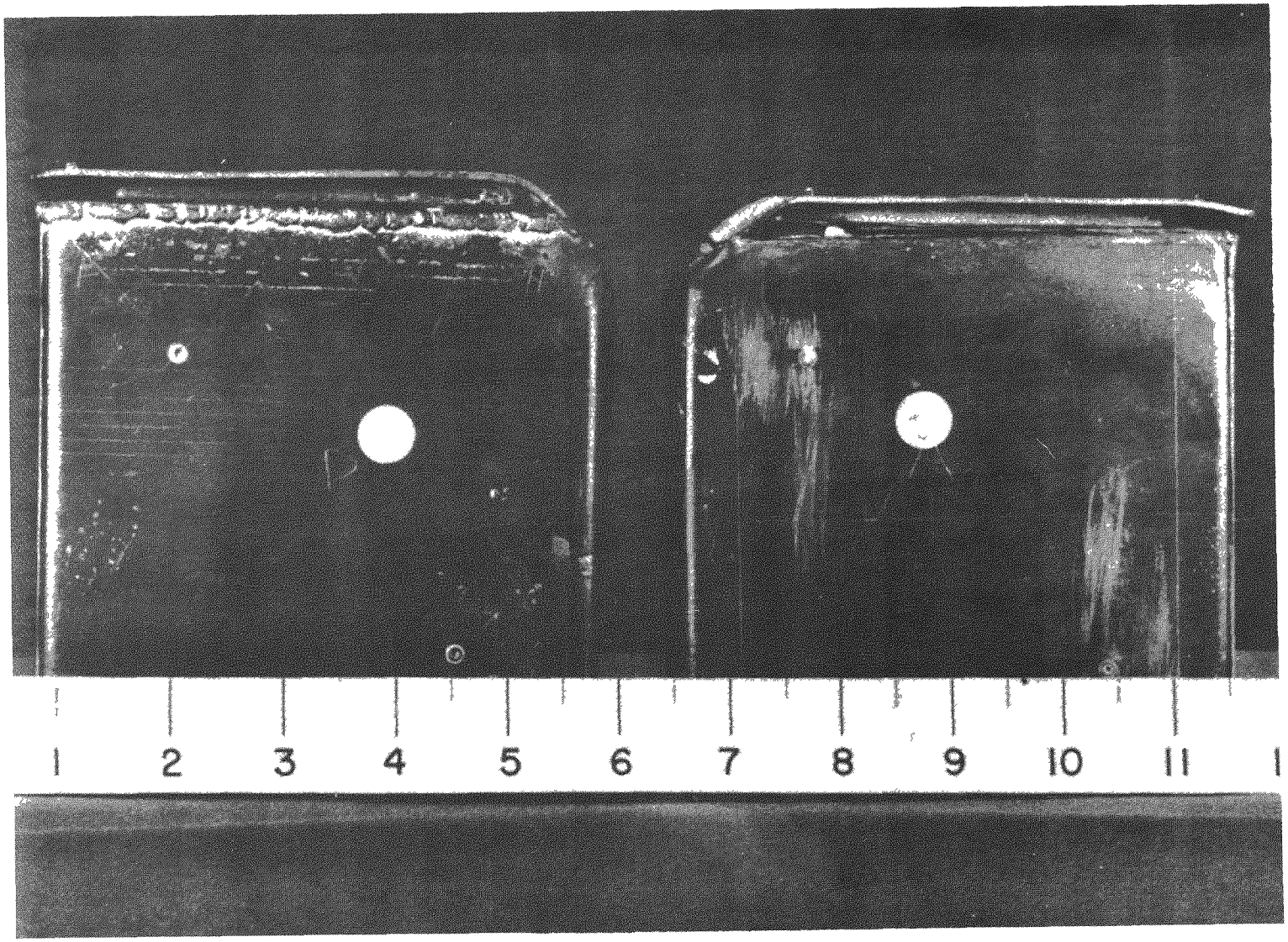


FIG. 6 - DAMAGE TO CUBIC MODEL CASKS FROM IMPACT ON LID EDGE

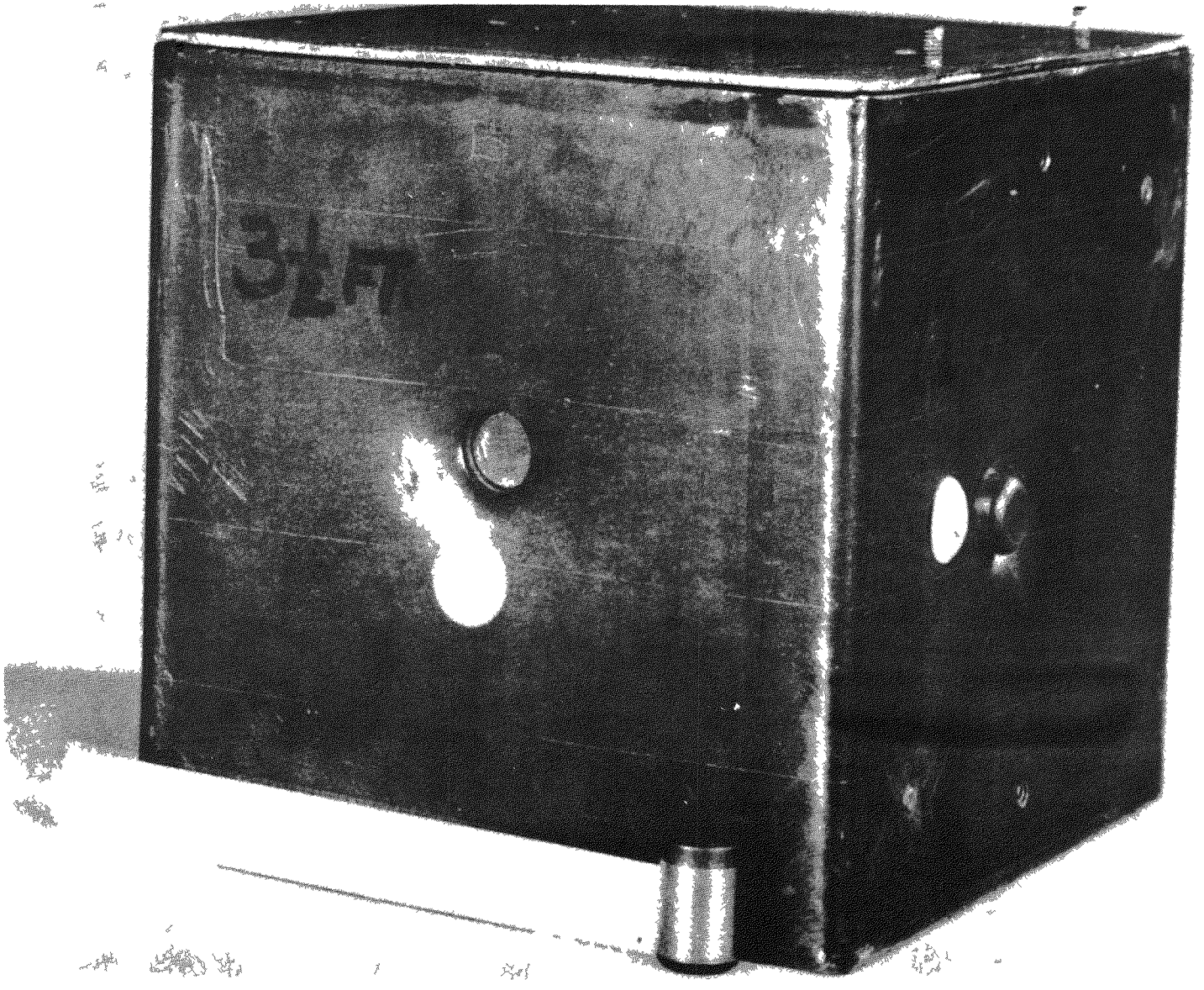
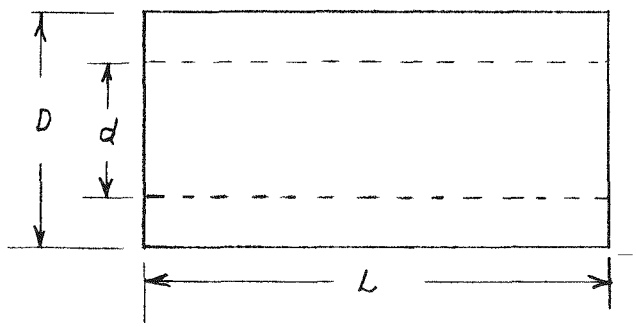


FIG. 7 - PENETRATING IMPACTS ON CUBIC MODEL CASK

MODEL & FULL SIZE CASK DIMENSIONS



	MODEL	FULL SIZE
L	9.864 IN.	36 IN.
D	4.932 IN.	18 IN.
d	2.809 IN.	10 1/4 IN.
WT. (INCL. LIDS)	55 lbs.	2720 lbs.

TITLE COMPARISON OF MODEL (.274 SCALE) DROP TEST DATA WITH THAT OF ORNL DATA ON 1.4 TON CYLINDRICAL CASK

FIG. 8 -

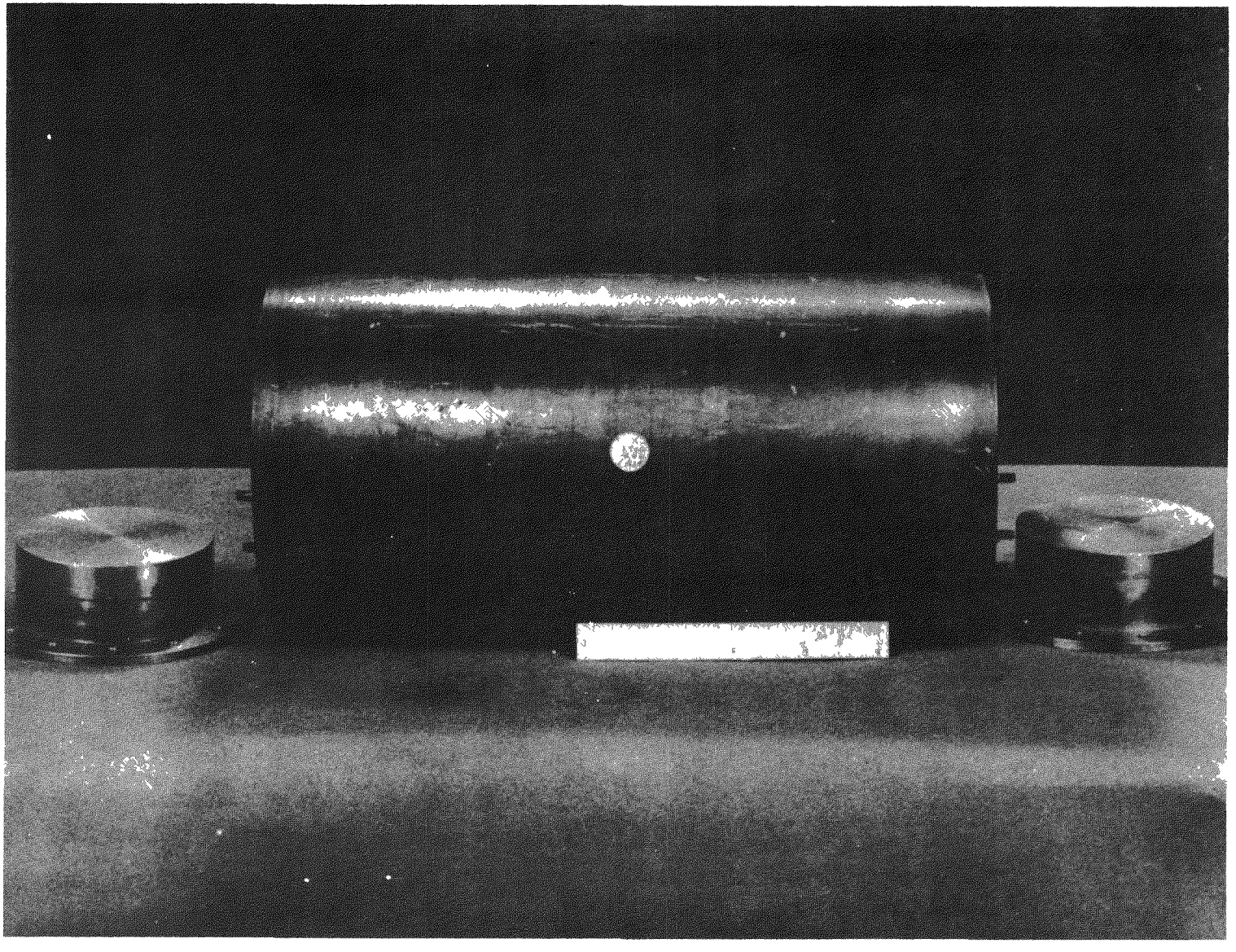


FIG. 9 - SIDE VIEW OF SCALE MODEL OF ORNL 1.4 TON CYLINDRIC CASK (.274 SCALE)

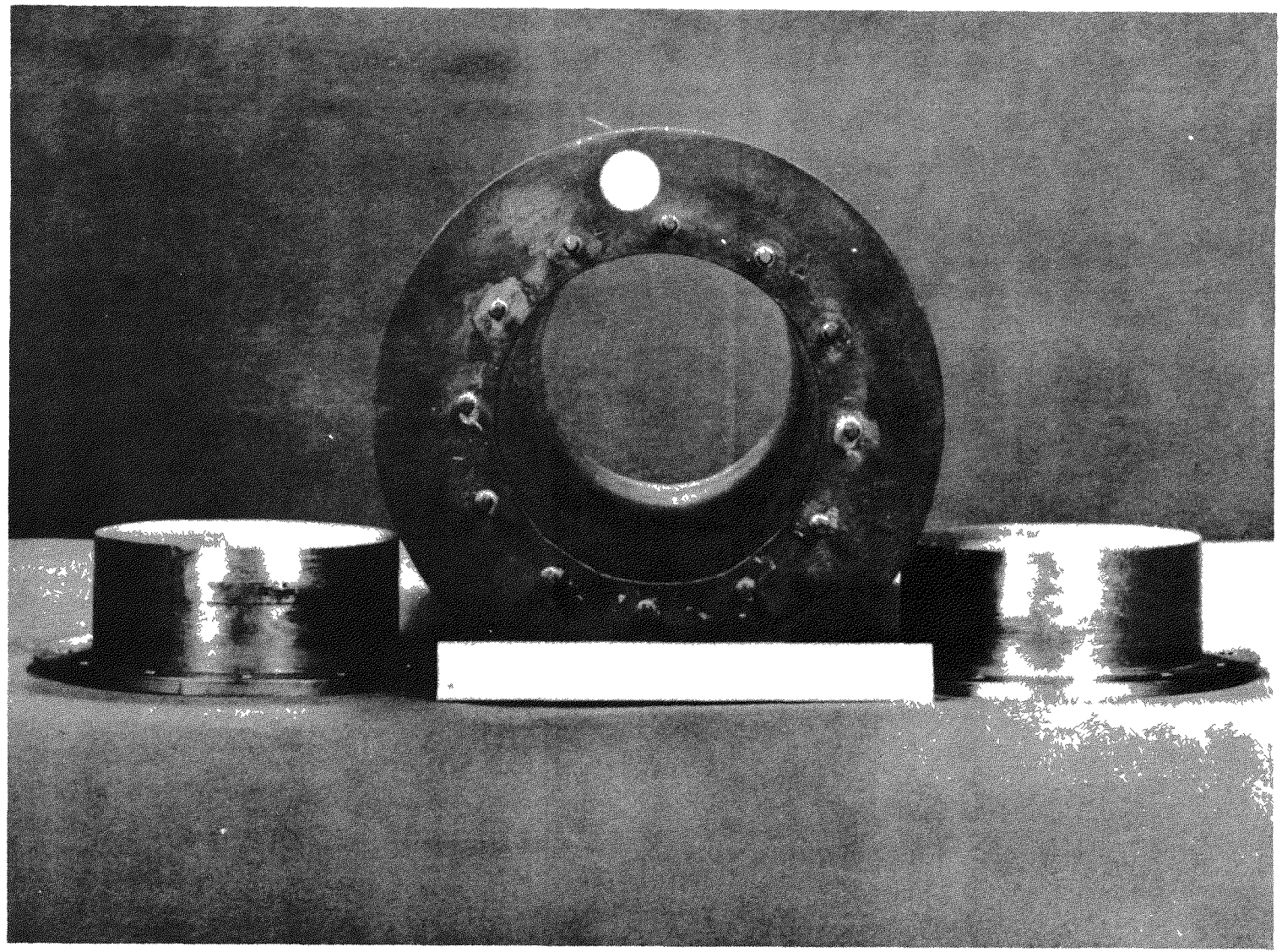


FIG. 10 - END VIEW OF SCALE MODEL OF ORNL 1.4 TON CYLINDRIC CASK (.274 SCALE)

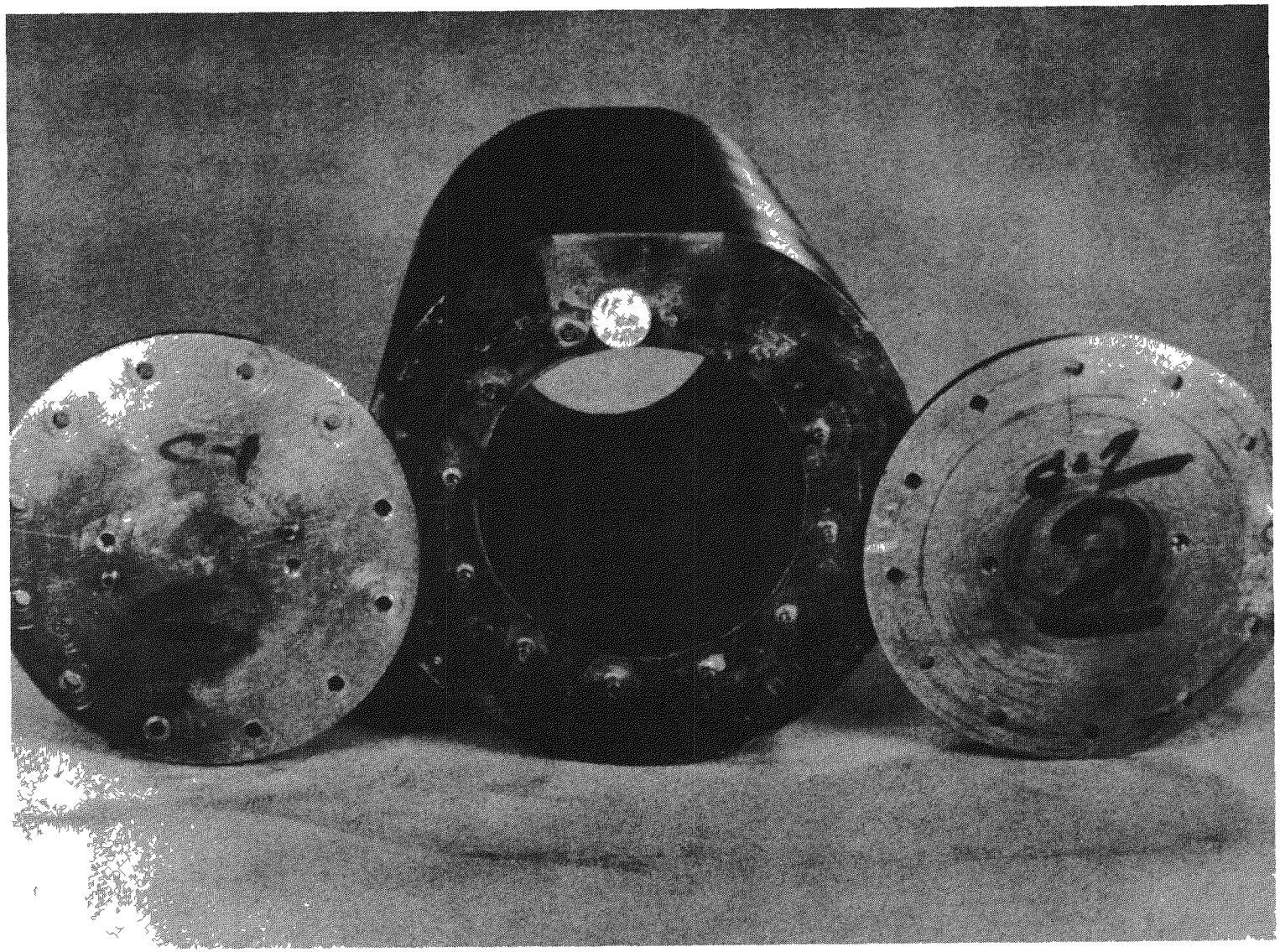
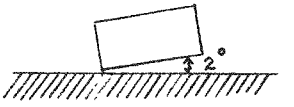
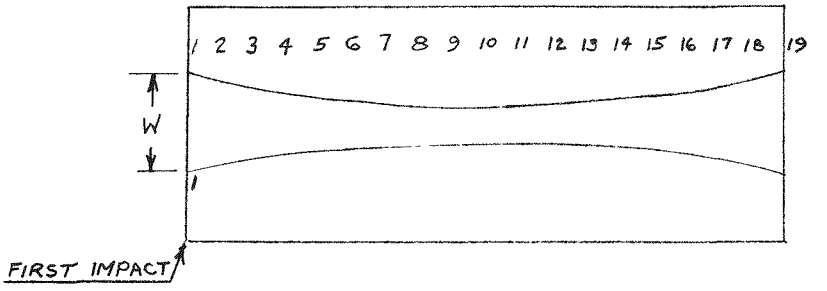


FIG. 11 - DAMAGE FROM 15 FT. DROP ON SIDE (SCALE MODEL OF ORNL CASK)

DESCRIPTION OF TEST : 15 FT. DROP - 2° FROM HORIZONTAL





WIDTHS OF FLATTENED SECTION FROM IMPACT END

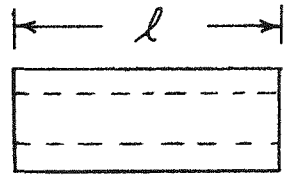
POSITION FROM IMPACT END	(.274 SCALE) MODEL RESULTS (IN.)	PREDICTED FULL SIZE (IN.)	ORNL FULL SIZE RESULTS (IN)
W1-1	1.454	5.31	5 1/4
W2-2	1.100	4.02	4 5/8
W3-3	1.040	3.80	3 3/4
W4-4	1.000	3.65	3 3/8
W5-5	.910	3.32	3 1/4
W6-6	.840	3.07	3 1/8
W7-7	.840	3.07	3
W8-8	.840	3.07	2 7/8
W9-9	.770	2.81	2 3/4
W10-10	.770	2.81	2 5/8
W11-11	.860	3.14	2 3/4
W12-12	.870	3.18	3
W13-13	.880	3.21	3
W14-14	.870	3.18	3 1/4
W15-15	.930	3.39	3 1/2
W16-16	.990	3.61	3 1/2
W17-17	1.090	3.98	4
W18-18	1.090	3.98	3 3/4
W19-19	1.234	4.50	4 3/4

FIG. 12 -

TITLE COMPARISON OF MODEL (.274 SCALE) DROP TEST DATA WITH THAT OF ORNL DATA ON 1.4 TON CYLINDRICAL CASK

MAXIMUM COMPRESSION OF INNER CYLINDER

15 FT. DROP – 2° FROM HORIZONTAL



POSITION FROM IMPACT END	(.274 SCALE MODEL) MAX. COMPRESSION (IN.)	PREDICTED MAX. COMPRESSION FULL SIZE (IN.)	MAX. COMPRESSION FULL SIZE - ORNL TEST RESULTS (IN.)
.125l	0.063	0.230	0.244
.250l	0.078	0.285	0.381
.417l	0.090	0.328	0.375
.583l	0.086	0.314	0.358
.750l	0.075	0.274	0.311
.875l	0.051	0.186	0.217

TITLE COMPARISON OF MODEL (.274 SCALE) DROP TEST DATA WITH THAT OF ORNL DATA ON 1.4 TON CYLINDRICAL CASK

FIG. 13 -

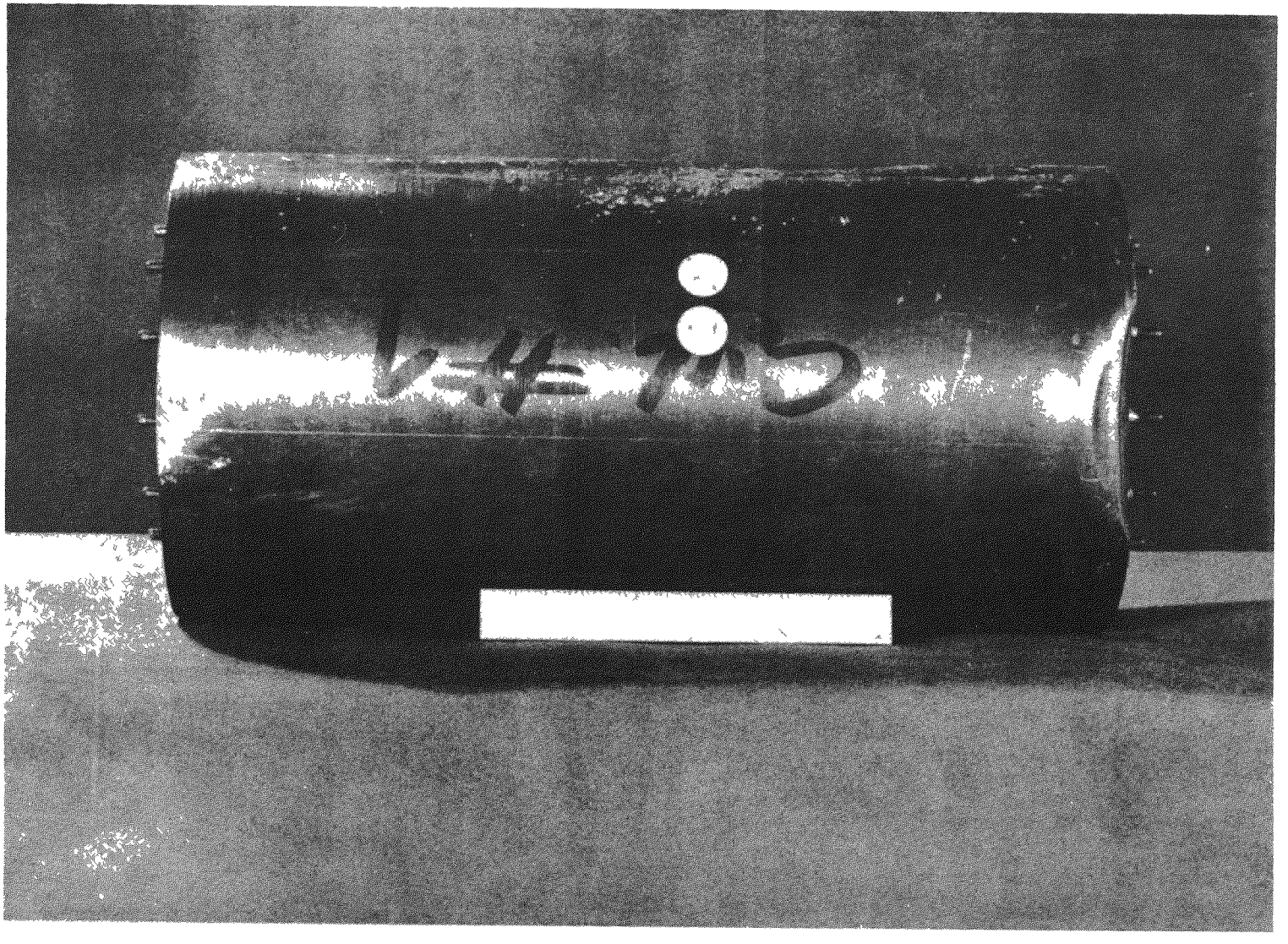


FIG. 14 - DAMAGE FROM 15 FT. DROP AT 45° ON CORNER - SIDE VIEW
(SCALE MODEL OF ORNL CASK)

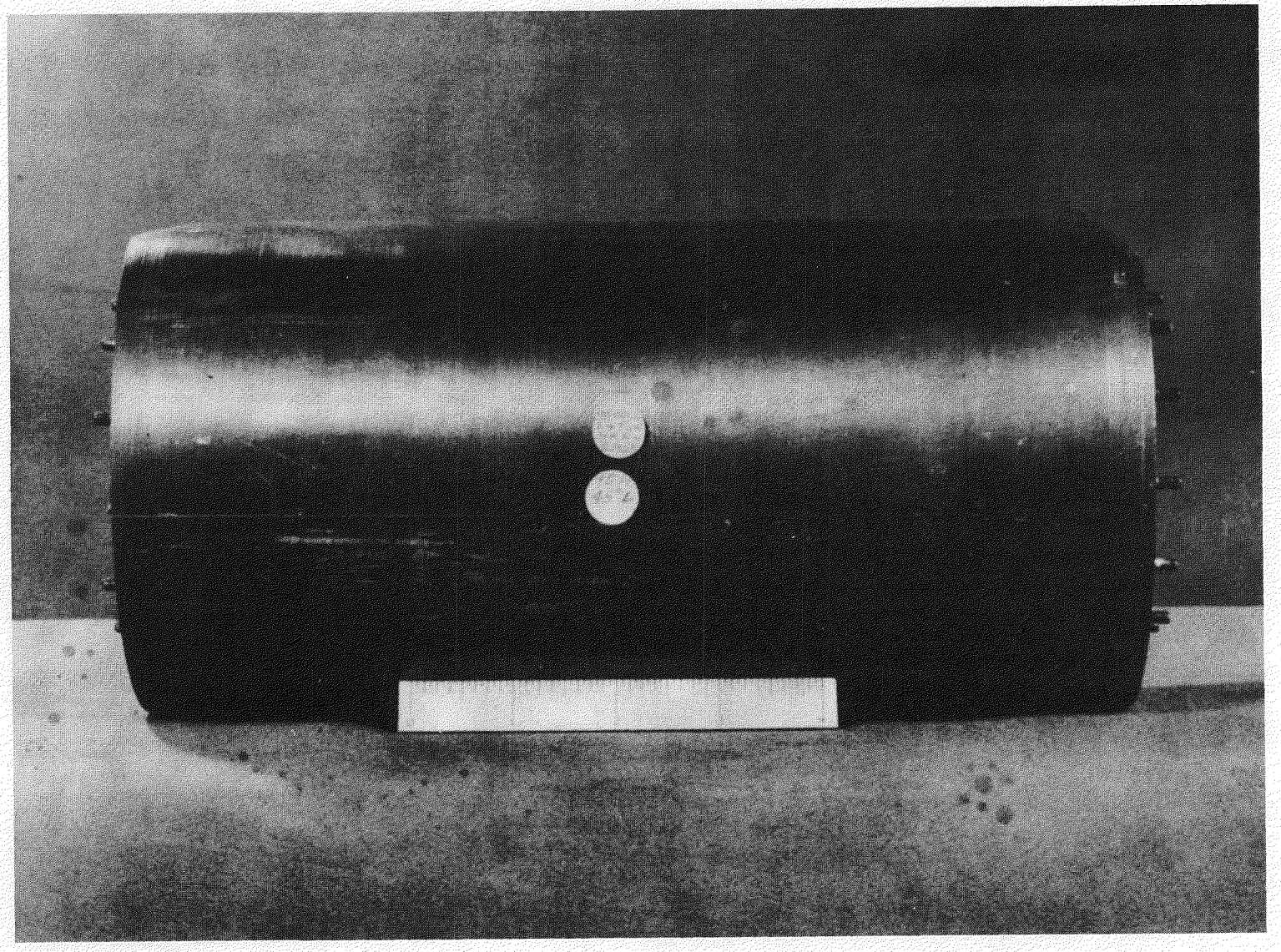


FIG. 15 - DAMAGE FROM 15 FT. DROP AT 45° ON CORNER - SIDE VIEW
(SCALE MODEL OF ORNL CASK)

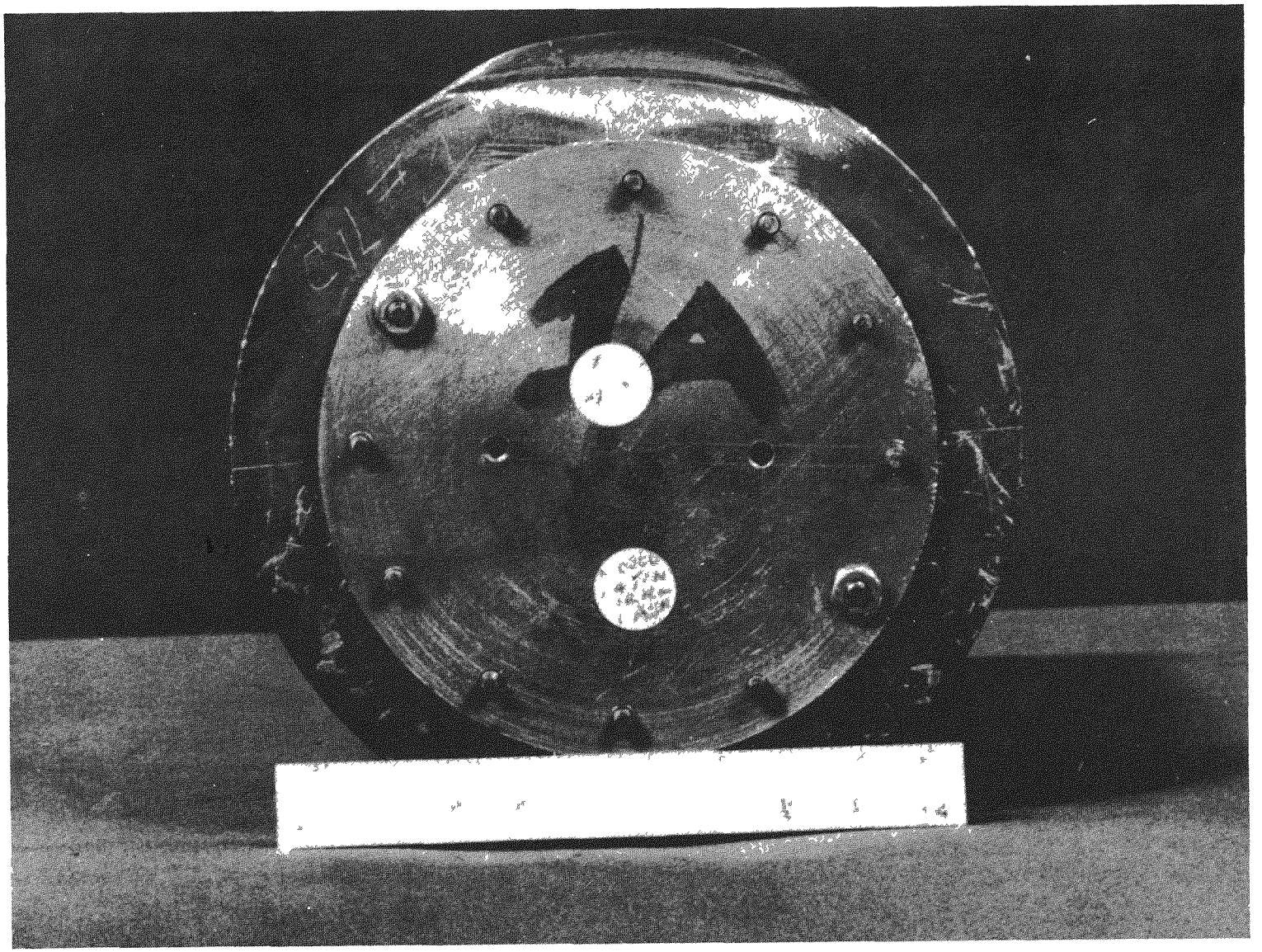
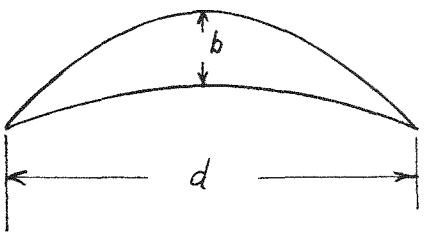
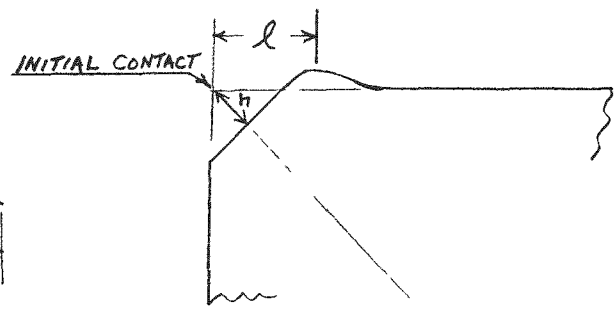


FIG. 16 - DAMAGE FROM 15 FT. DROP AT 45° ON CORNER - END VIEW
(SCALE MODEL OF ORNL CASK)

TEST RESULTS OF 45° ⅄ DROP



AREA IN CONTACT WITH ANVIL



	(.274 SCALE MODEL) TEST RESULTS	PREDICTED FULL SIZE	ORNL FULL SIZE TEST RESULTS
d	2.44 IN.	8.9 IN.	9 1/2
ℓ	0.69 IN.	2.5 IN.	2 3/8
b	0.44 IN.	1.6 IN.	———
h	0.295 IN.	1.1 IN.	———
AREA	0.68 IN^2	9 IN^2	———

TITLE COMPARISON OF MODEL (.274 SCALE) DROP TEST DATA WITH THAT OF ORNL DATA ON 1.4 TON CYLINDRICAL CASK

FIG. 17 -

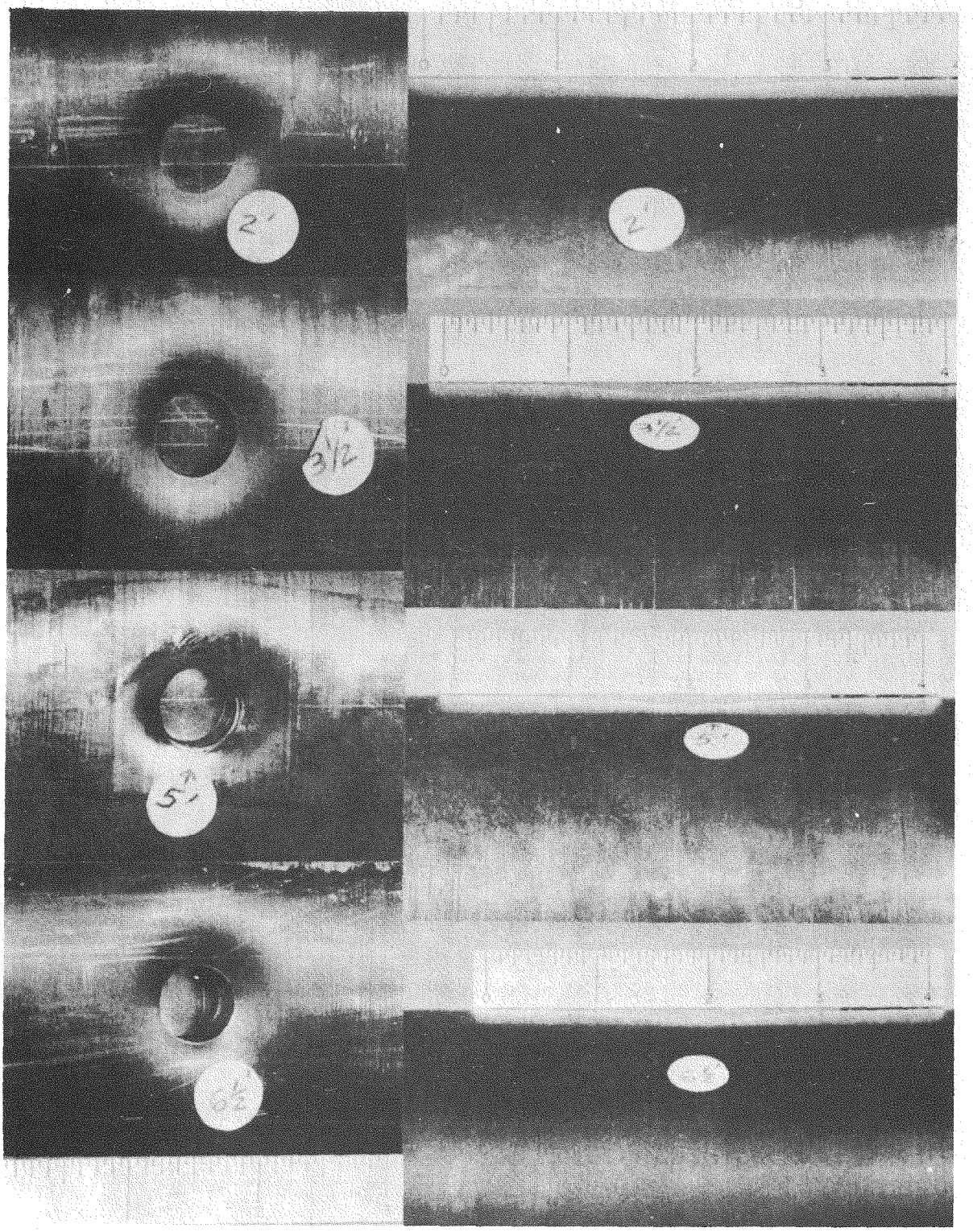


FIG. 18 - DAMAGE FROM PENETRATING IMPACTS ON SIDE (SCALE MODEL OF ORNL CASK)

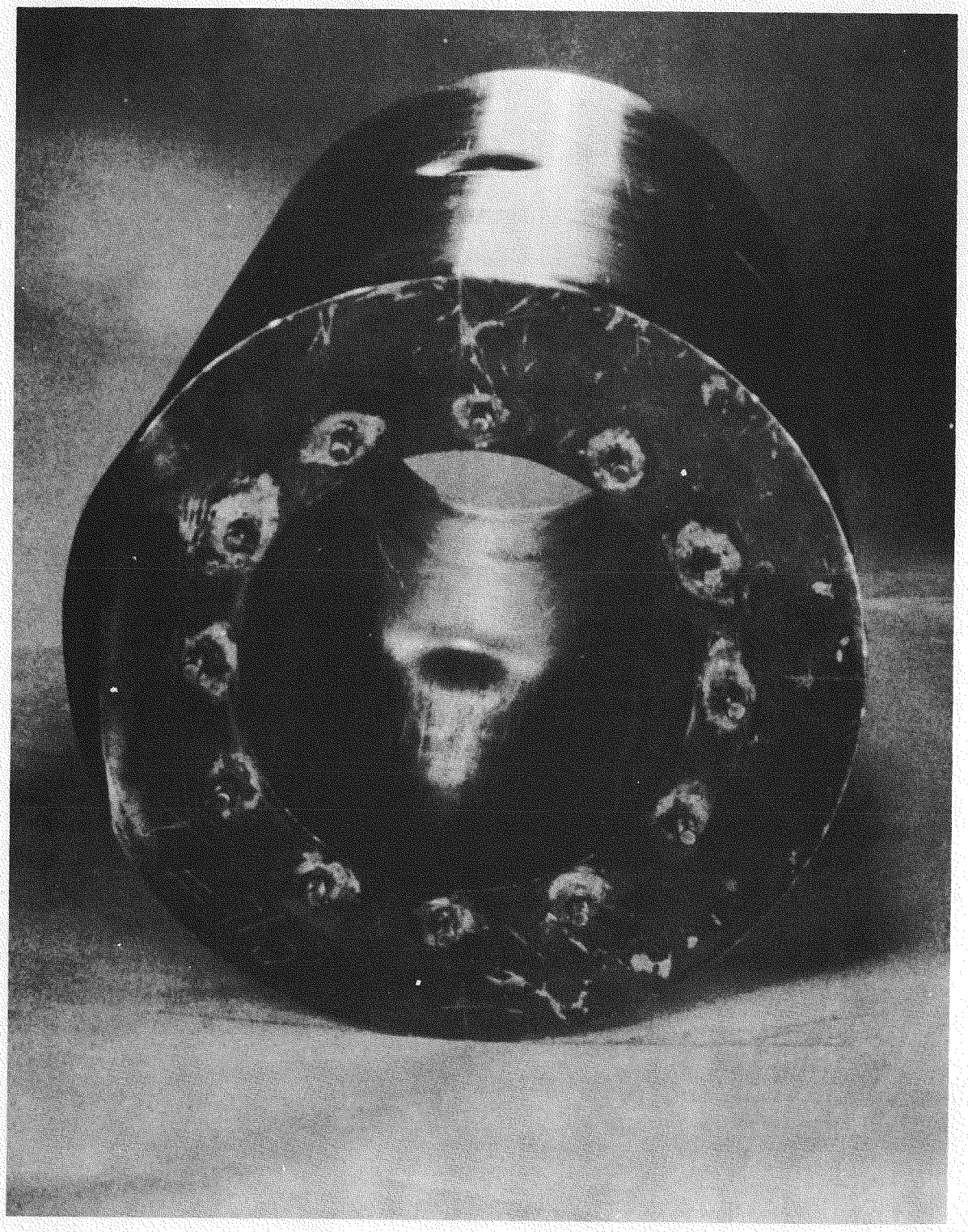


FIG. 19 - BULGE OF INNER SHELL FROM 6.5 FT. PENETRATING IMPACT ON SIDE (SCALE MODEL OF ORNL CASK)

PENETRATION DATA

0.274 SCALE MODEL RESULTS

3½ FT. DROP HEIGHT

PENETRATOR	PENETRATION (IN)	PREDICTED FULL SIZE PENETRATION (IN.)
C.R. PIN 0.003" RADIUS	0.151	0.55
C.R. PIN < 0.0003" RADIUS	0.159	0.58
HARDENED PIN < 0.0003" RADIUS	0.205	0.75

COMPARISON DATA

DROP HT. (FT.)	MODEL PENETRATION-TEST RESULTS (IN)	PREDICTED FULL SIZE PENETRATION (IN)	FULL SIZE PENETRATION TEST RESULTS (IN)
2	0.013	0.047	3/16
3½	0.151	0.551	7/8
5	0.268	0.978	1½
6½	0.534	1.95	2¼

FIG. 20 -

TITLE COMPARISON OF MODEL (.274 SCALE) DROP TEST DATA WITH THAT OF ORNL DATA ON 1.4 TON CYLINDRICAL CASK

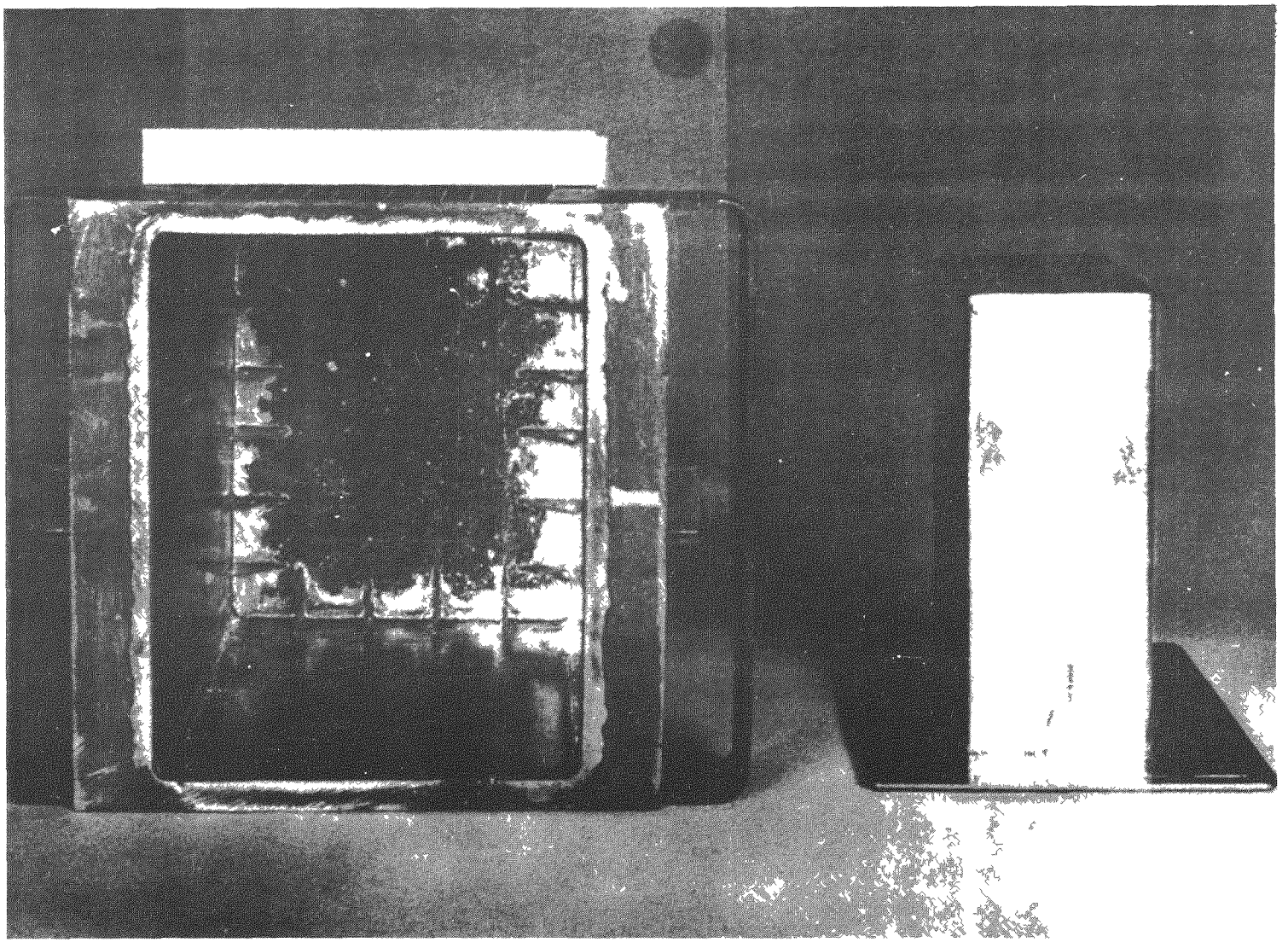


FIG. 21 - COMPONENTS OF SCALE MODEL OF 15 TON SLUG CASK (.115 SCALE)

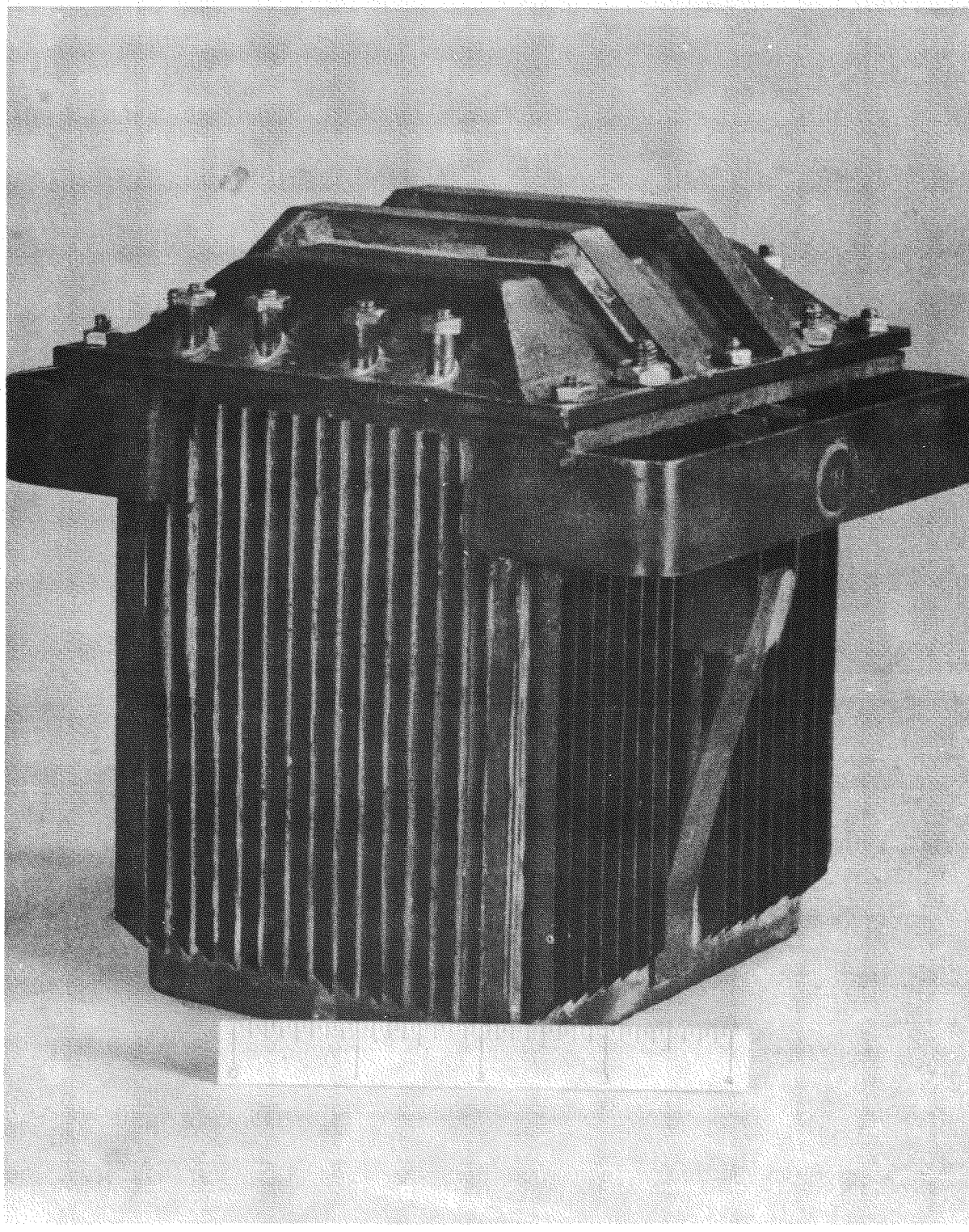


FIG. 22 - ASSEMBLED SCALE MODEL OF 15 TON SLUG CASK (.115 SCALE)

Remarks by Mr. Clark: The price of testing the models is considerabley more than the price of fabrication. The measurement of these models accurately is a rather difficult thing, costs a good bit. As a guess, perhaps two or three or four times the cost of the model.

SESSION III CONT'D
WEDNESDAY MORNING - DECEMBER 5, 1962

Mr. Arnold B. Joseph, Division of Reactor Development, U. S. Atomic Energy Commission, Session Chairman presiding.

The Division of Reactor Development is largely responsible for supporting some of the safety work that you have heard about in the past few days.

One of the blessings of being at the end of an agenda such as we have had is that we can take potshots at all the papers that preceded us, and we don't have to be too concerned with protective measures.

I will leave this up to our individual speakers this morning, to take whatever advantage of it they can.

On the first day, we heard Mr. Langhaar and Mr. Aikens discuss many of the problems that designers and regulators are concerned with in making and using containers in a safe fashion.

I don't know if you realize this, but we are somewhat on the frontiers of a branch of science. We can also categorize all the problems that we have talked about into two broad categories. These have to do with problems of measurement and problems of understanding or theory in understanding the measurements.

Getting back to this brontiers business, we have heard discussions of problems of measurements of dynamics, measurement of energy in very short cycles and very high pulses. This is bordering on solid state physics on something of a micro scale. We also touched somewhat on the problems of heat transfer, problems of making these measurements, without disrupting the experiments.

Today we will hear a little bit more about work on the frontiers of this branch of science or engineering. These will be somewhat different from what we have heard in the last two days. One of the papers will be in the direction of circumventing some of the problems of design of containers by applying alternate measurements, and the others will be concerned with making new measurements and understanding these measurements. These would be measurements of the energy systems.

The first paper on the agenda this morning is concerned with a system for circumventing some of the container problems by applying alternate protective measures.

Mr. C. W. Smith, an engineer with the Chemical Process Department, at the Hanford Atomic Products Operation, operated by the General Electric Company, will be our first speaker. His group is responsible for putting the fission products in such form that they can be shipped and designing the containers and systems for shipping, loading the containers and getting them off the Hanford property.

APPLICATION OF EXTERNAL ENERGY ABSORBERS TO LARGE FISSION PRODUCT SHIPPING CASKS

Prepared by

D. W. McLenegan C. W. Smith

Hanford Atomic Products Operation
General Electric Company

E. A. Ripperger J. E. Breen

Structural Mechanics Research Laboratory
University of Texas

I. INTRODUCTION

At the present time Hanford is engaged in, or is planning, shipment of isolated, concentrated, specific fission products such as cesium-137, strontium-90, and cerium-144. Although the problems of radiation shielding and heat dissipation are not vastly different from other shipments of materials such as irradiated fuel elements or radiation sources, the forms of these fission product compounds are quite different. Hanford is primarily a bulk supplier of fission products and the materials are shipped in an intermediate form which is suitable for further processing into the final product form. Shipments are currently being made either as a dry powder or as a cation adsorbed on a bed of inorganic ion exchange material and covered with water. Shipments of strontium-90 will contain typically 150,000 to 350,000 curies of strontium-90 plus the attendant strontium-89. Shipments of cerium will contain from 400,000 curies of cerium-144 plus other radio-impurities when shipped as a cerium-rare earth mixture to approximately 1,000,000 curies of cerium-144 when shipped as a refined cerium product. The very high radio-toxicity of these materials dictate a very conservative approach to the design of containers for these fission product shipments.

II. DESIGN CRITERIA DEVELOPMENT

Design of the first cask was begun in early 1960. At that time there were no regulations covering the shipment of large quantities of these materials and no established criteria covering the design of these types of containers. Then in March of 1960, the AEC Division of Licensing and Regulations published the first draft of the proposed regulation 10 CFR 72, for probable implementation after a brief discussion period. At that time, we were requested to design the fission product shipping cask to meet the

applicable portions of this regulation, which was intended for irradiated fuel elements. The portion of this regulation, with the greatest consequence in the design, required that the cask withstand impact with a solid surface while traveling at 44 fps. In addition to these requirements, the Bureau of Explosives, in commenting on an earlier proposed cask design, had stated that the casks of this type should be self-sustaining for 48 hours following failure or loss of the heat transfer mechanism. The possibility of these casks being involved in an oil or chemical fire was also being considered. About this time, a train wreck in California which was accompanied by a gasoline fire, demonstrated that this hazard was real and should be considered in designing casks for cross-country transport of fission products.

As a result, the cask design criteria which were developed required that the cask provide adequate radiation shielding, dissipation of the decay heat, and complete containment of the fission products for all conditions of normal transport and for emergency conditions which were defined as impact with an unyielding surface while traveling at 44 fps followed by either complete loss of heat dissipation for 48 hours or immersion in a fire at 2500° F for 2 hours. In addition the cask had to be operable either remotely or semi-remotely and had to be easily decontaminated.

Although the basic design criteria can be stated simply, the application of these criteria to a given cask design is considerably more complicated due to conflicts between normal and emergency requirements. For instance, the lead which is necessary for radiation shielding increases the problems of cask handling and impact protection. Likewise, provision of a path of low thermal resistance for normal heat dissipation would result in increased heat input should the cask be involved in a fire. The heavy structural members which are required for structural integrity may interfere with normal heat dissipation and handling capabilities.

III. DESIGN

A. Concepts

In arriving at the final designs which it was felt satisfied these criteria, many alternates were considered. One of the first alternative designs considered was an extremely rugged cask capable of withstanding the required conditions of impact. However, it was determined that regardless of the rigidity of the cask, it was impossible to predict the degree of deformation. Secondly, even if the deformation of the cask could have been predicted, it would have been impossible to assure that this amount of deformation did or did not result in failure of the cask.

The next alternate considered was an extremely rigid structure around the cask, but this was determined to be infeasible both from the standpoint of predicting the behavior of such a structure under impact loading and from its size and weight.

The final concept was to provide a material with a known crushing strength between the cask which was to be protected and the impact surface. This concept was utilized for the final design, since it provided a method for demonstrating by calculations that the design did satisfy the design criteria. In addition, this concept provided considerable flexibility in meeting the criterion regarding protection from fire.

B. Equipment Description

The shipping container design consists of three basic parts: 1) a product container for collecting and containing the fission products; 2) a cask to provide radiation shielding and additional surface for heat transfer; and 3) a cask container completely surrounding the cask and providing protection against impact in all directions.

1. Product Container

A typical product container (Figure 1) is an annular shaped, stainless steel pressure vessel designed to withstand the pressures from radiolytic or thermal decomposition of the fission product compounds. The annular container shape was chosen for its heat transfer characteristics. This configuration provides a large surface area per unit volume and shortens the heat transfer path in the container thereby favoring low maximum product temperatures. The fission products are brought into the product container as a slurry, distributed around the annulus, and collected on a stainless steel, wire cloth filter screen. The collected fission product compound is then dried and stabilized for shipment by applying additional heat. At the receiving site the fission products are removed by dissolution and back-flushing.

2. Cask

The cask is an externally finned, lead shielded, stainless steel cylinder completely surrounding the product container. The product container is attached to the cask cover which contains the process connections for loading and unloading the product container. The cask cavity also contains an electric heater for applying additional heat to dry and stabilize the fission product filter cake and coils to cool the cask for loading and unloading operations. The cask cavity is filled with a low melting alloy to provide a thermal bond between the product container, the heater, the coils and the inside of the cask cavity.

For normal heat dissipation, the low melting alloy picks up the heat at the product container surfaces and transfers it to the inner wall of the cask. The heat is then conducted through the walls of the cask to the cask surface where it is dissipated to the air by natural convection. The 1/2 inch thick by 4-inch high fins which extend radially from the cask provide additional heat transfer surface. This extended surface area results in surface temperatures of less than 250° F with an ambient air temperature of 100° F. The resistance to heat conduction through the composite stainless steel lead walls has been minimized by a metallurgical bond between the lead and the stainless steel.

Two size casks have been designed. The HAPO-II cask (Figure 2) is 40-inches in diameter by 56-inches high and weighs 18,000 pounds. The HAPO-I cask (Figure 3) is 52 inches in diameter by 71-inches high and weighs 40,000 pounds.

3. Cask Container

Once it was found feasible to provide a structure around the cask as protection against impact, it became clear that the same means could provide substantial protection against excessive heat input

HAPO II FILTER - CONTAINER

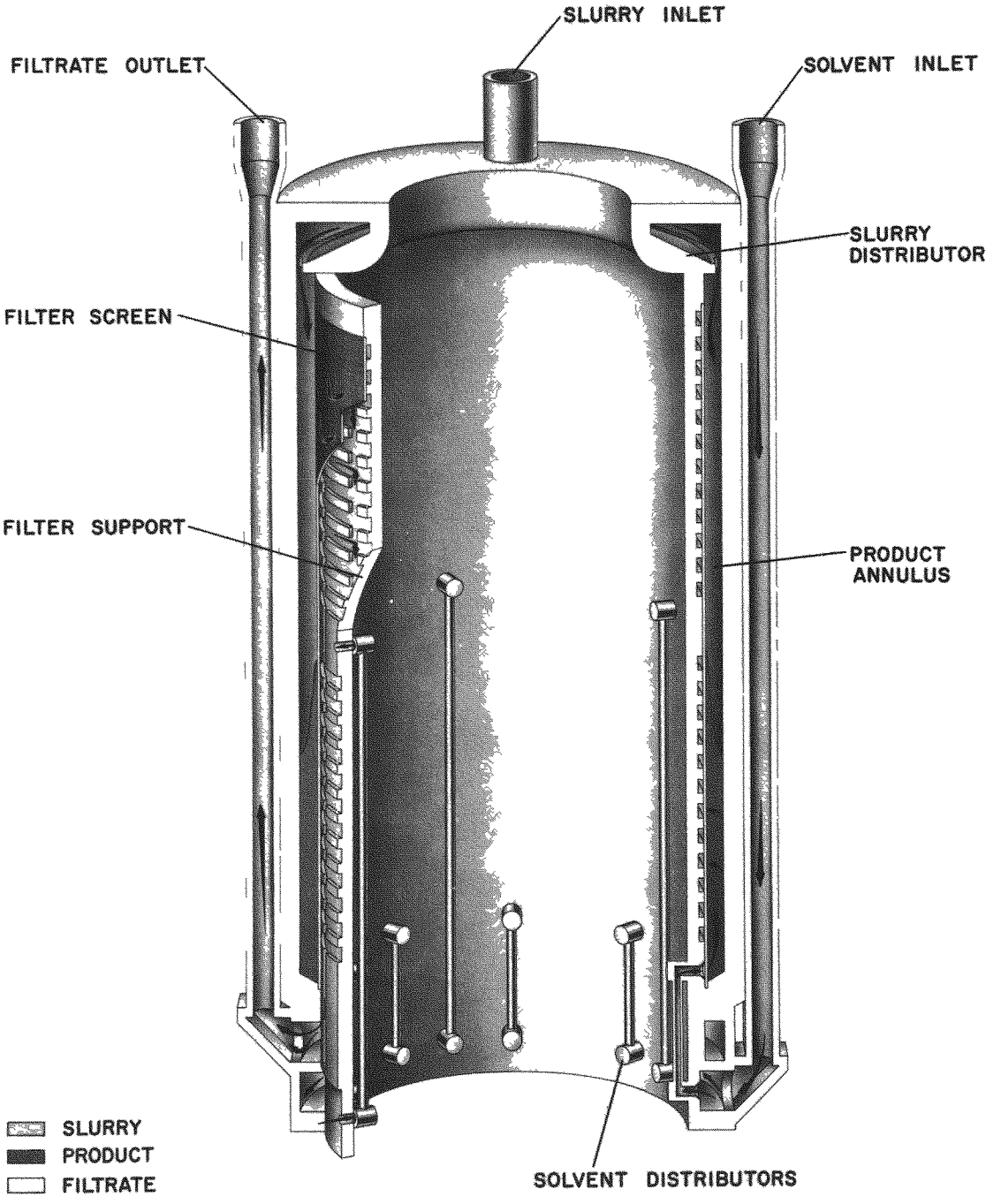


FIGURE 1

from an external fire, and still permit the required heat dissipation from the cask under normal conditions.

As regards impact, an early draft of a Federal regulation required that the shipment be protected in a 30-foot free fall on an unyielding surface. This requirement, which was accepted as reasonable, has had a strong influence on Hanford designs. It was recognized that these conditions amounted to enormous impact forces, which could not be predicted accurately as a basis for stress analysis and design. (Later tests indicate that the impact accelerations may be as high as 2,000-3,000 G.) So the choice lay between designing a very massive structure like a gun turret or providing a shock absorber which would be expendable under extreme conditions but which would protect the cask.

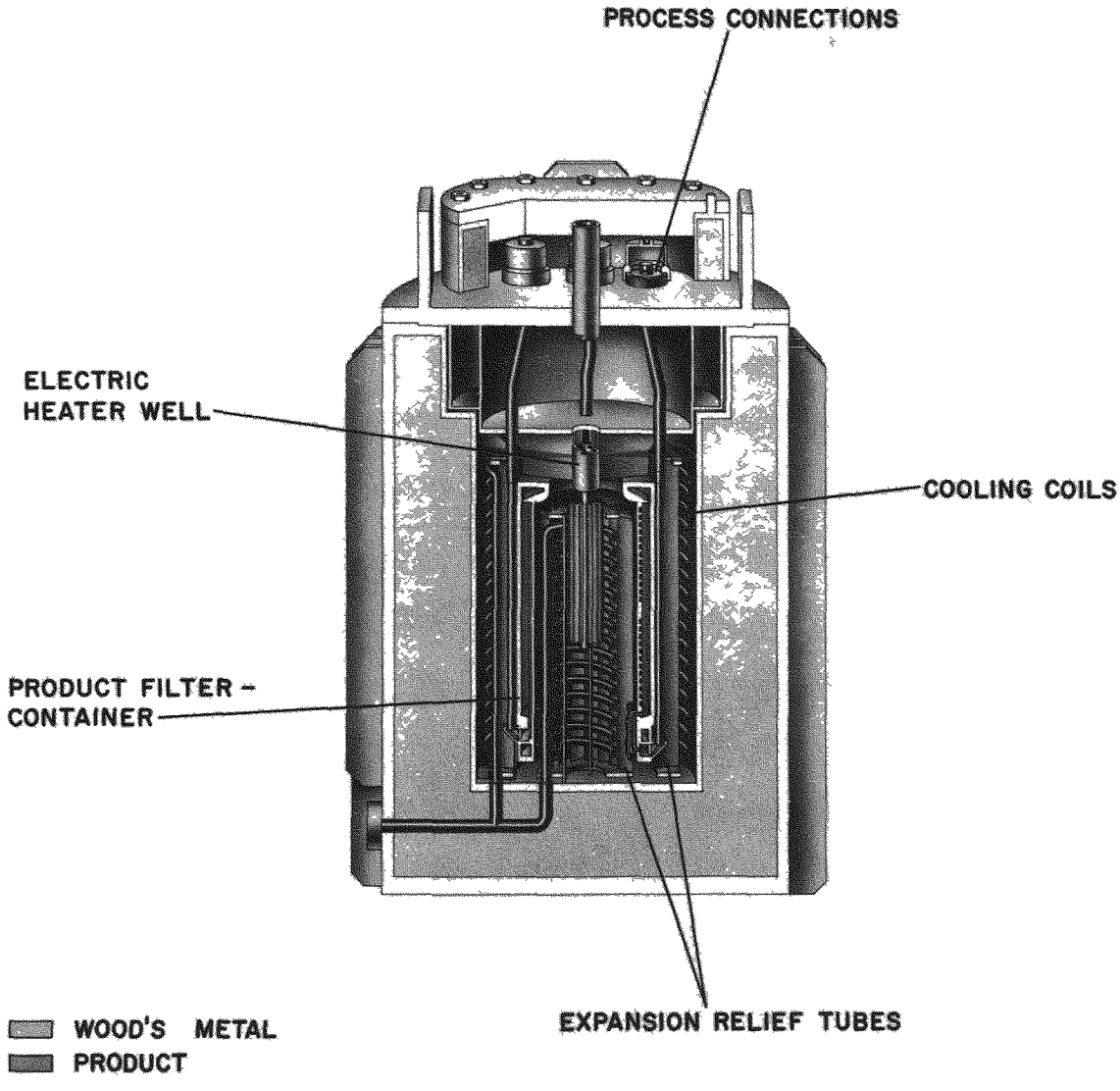
To date several combinations of cask and container have been designed, all using the same general concept, and two of these have seen considerable cross-country service. The general concept of protective cask container (Figure 4) involves a vertical steel cylinder reinforced at top and bottom by strong spiders of I-beams and plates. Within this outer shell are three concentric cylinders of thinner steel; the innermost one fits reasonable closely around the cask fins, but has enough clearance so that the cask can be lifted out after unbolting the top spider. Under a heavy impact the cask and the three inner cylinders can move radially within the outer cylinder. The three annular spaces contain buffer elements, designed to absorb the kinetic energy of the cask with forces equivalent to about 50 G. Above and below the cask are buffer elements to cushion an endwise impact. Edge impacts are considered as a combination of radial and axial forces, with the heavy spiders holding the container assembly in shape. This has been substantiated in drop tests.

It was also envisioned that impact on a rough, irregular surface might result in piercing the outer shell of the container, but only after bending this shell and spreading the force over a wider surface at the next shell; in this way the piercing action would tend to become more nearly a uniform pressure at the cask surface. To date, however, protection has not been achieved against a 30-foot drop onto a rigidly-supported steel cylinder of small diameter.

Considering the thermal problem, air can be admitted through openings in the bottom spider, to flow upwards over the external fins of the cask and out through the top spider. These confined "chimney spaces" yield a good upward flow of coolant air over the cask surface and fins. As an alternative arrangement (Figure 5) where the heat dissipation requirement is smaller, the next-to-the-outer surface of the buffer can be used as a heat exchanger, with coolant air in an enclosed loop. For this case, the buffer is sealed at top and bottom, except for the outer annulus. This concept was used for a design involving a liquid shipment; here the entry of heat from an external fire must be retarded to prevent dangerous vapor pressure within the cask. Accordingly, the inner annulus of the container was insulated with lightweight fill material, around the buffer elements, to reduce thermal radiation inward to the cask.

In brief, various combinations of the same basic elements have been used to meet the principal requirements mentioned earlier, namely

HAPO II CASK



FICURE 2

HAPO I CASK

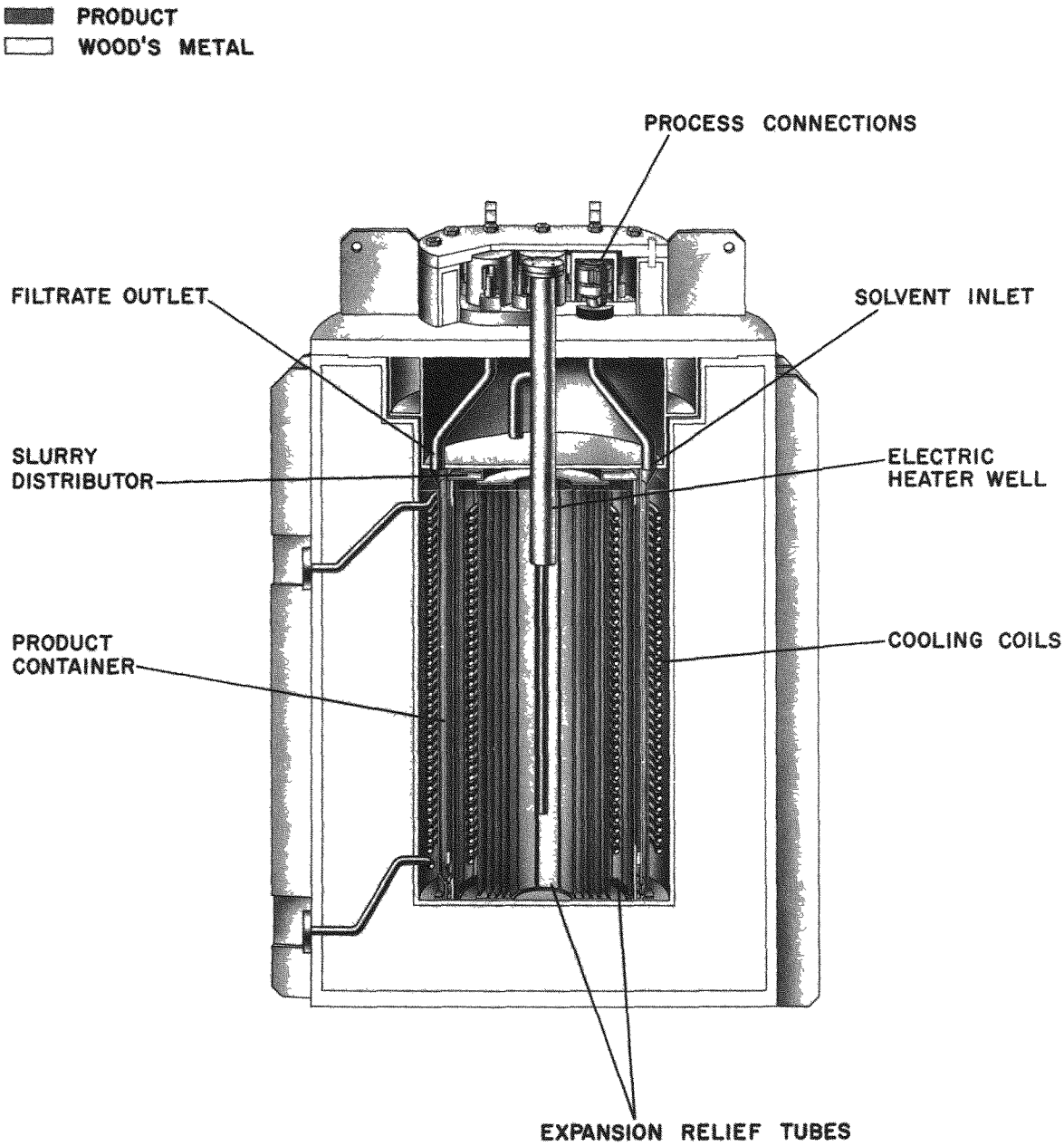


FIGURE 3

HAPO II CASK CONTAINER

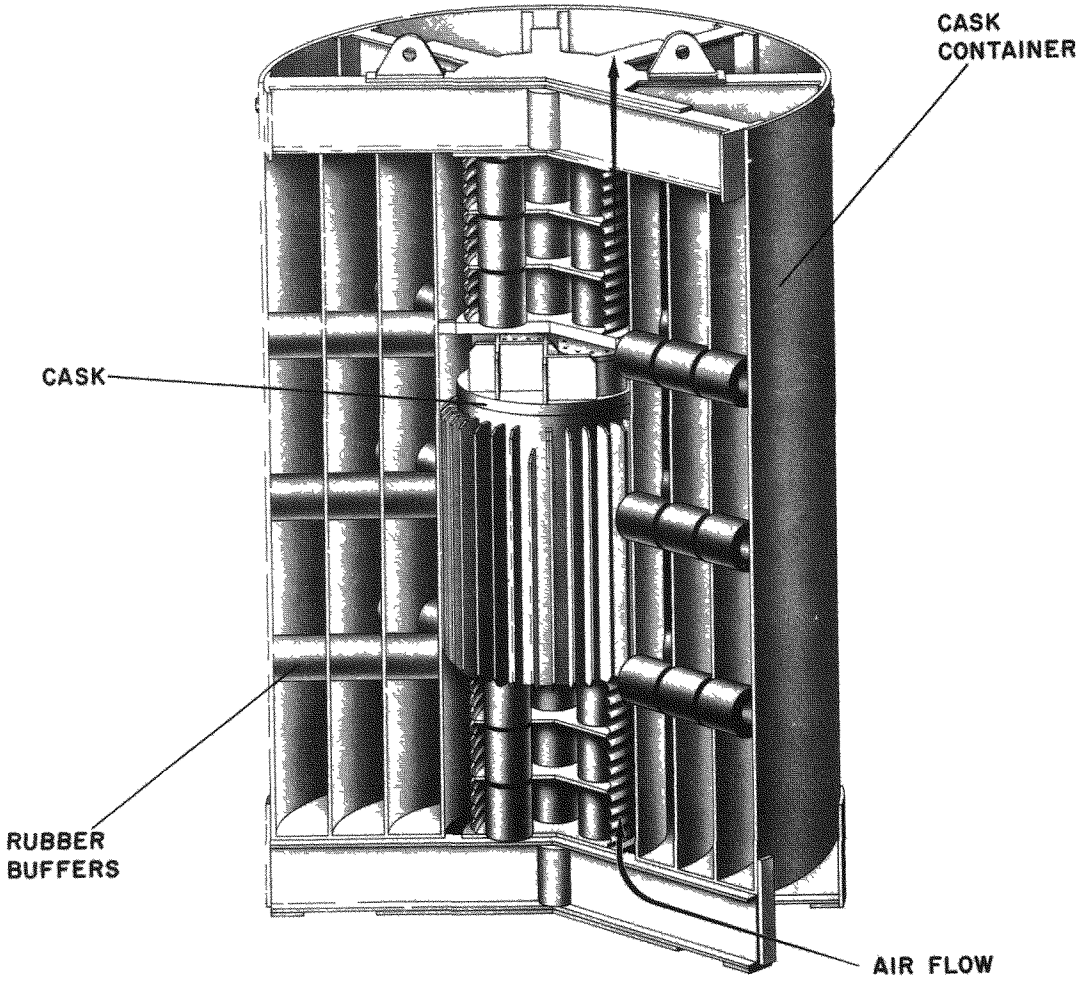


FIGURE 4

impact protection, provision for normal heat dissipation, and a defense against excessive heat input from an external fire.

From the standpoint of on-site handling, the cask container is a help rather than a hindrance, despite its additional weight. If there were no "buffering" container, the cask would presumably have to be strengthened, and this would result in a single piece excessively heavy for handling. Conversely, with the buffers to take care of major impacts during cross-country shipment, the cask can be removed from its container for separate handling at the loading and unloading points.

4. Energy Absorbers

The first of these container designs for the HAPO-I cask utilized hollow cylinders of relatively hard rubber as the energy absorbers, mounted radially and axially. Urgency required that existing technology be used as a basis; fortunately engineering and test data from private sources permitted the use of this material at high "specific energy", i.e., up to 2,000 in.-lbs. of energy absorption per cubic inch of material, and at very fast rates of compression under impact. Under these conditions the rubber becomes primarily an energy absorber with little rebound, and its stress-strain ratio (modulus of elasticity) is much higher than under slow compression. Both of these characteristics are favorable. However, for rubber compounds the force is proportional to the deflection (Figure 6) of the rubber. Therefore, to absorb the required kinetic energy of the cask without exceeding the allowable forces on the cask, requires a considerable depth of energy absorbing material. Another drawback which was recognized in advance is the stiffening of this synthetic rubber compound at winter temperatures, which will affect the buffer performance.

The HAPO-I cask weighs 40,000 lbs., is about 71-inches high and 52-inches in diameter, including the fins. The original container weighs 35,000 lbs., is 13 feet 8-inches high and 10-feet in diameter. These dimensions have required the use of a depressed bed car.

A second assembly, HAPO-II, was designed along similar lines for shipping a strontium compound. A lower rate of heat emission and weaker radiation energy permitted reductions of the size of inner cavity and the thickness of cask shielding, with correspondingly lighter weight and a smaller buffer. The cask weighs 18,000 lbs. and the buffer 23,000, making a total shipping weight of 41,000 lbs. This assembly is 12-feet high and of 8-feet diameter. It is easily accommodated on a railway flat-car of standard height.

Since these designs were made in 1960, internal improvements have been made in the casks, and some further designs have been made in relation to the varying demands for the products to be shipped but no new casks have been built. Extensive study has, however, been devoted to a lighter, smaller cask container for the HAPO-I (Cerium) cask (and potentially for the other casks).

Energy-absorbing materials other than rubber have been examined, looking towards size and weight reduction, and performance independent of climatic temperature. Of the materials examined, corrugated paper honeycomb and foamed plastics do not appear suited to the concentrated loads imposed by these compact, heavy casks.

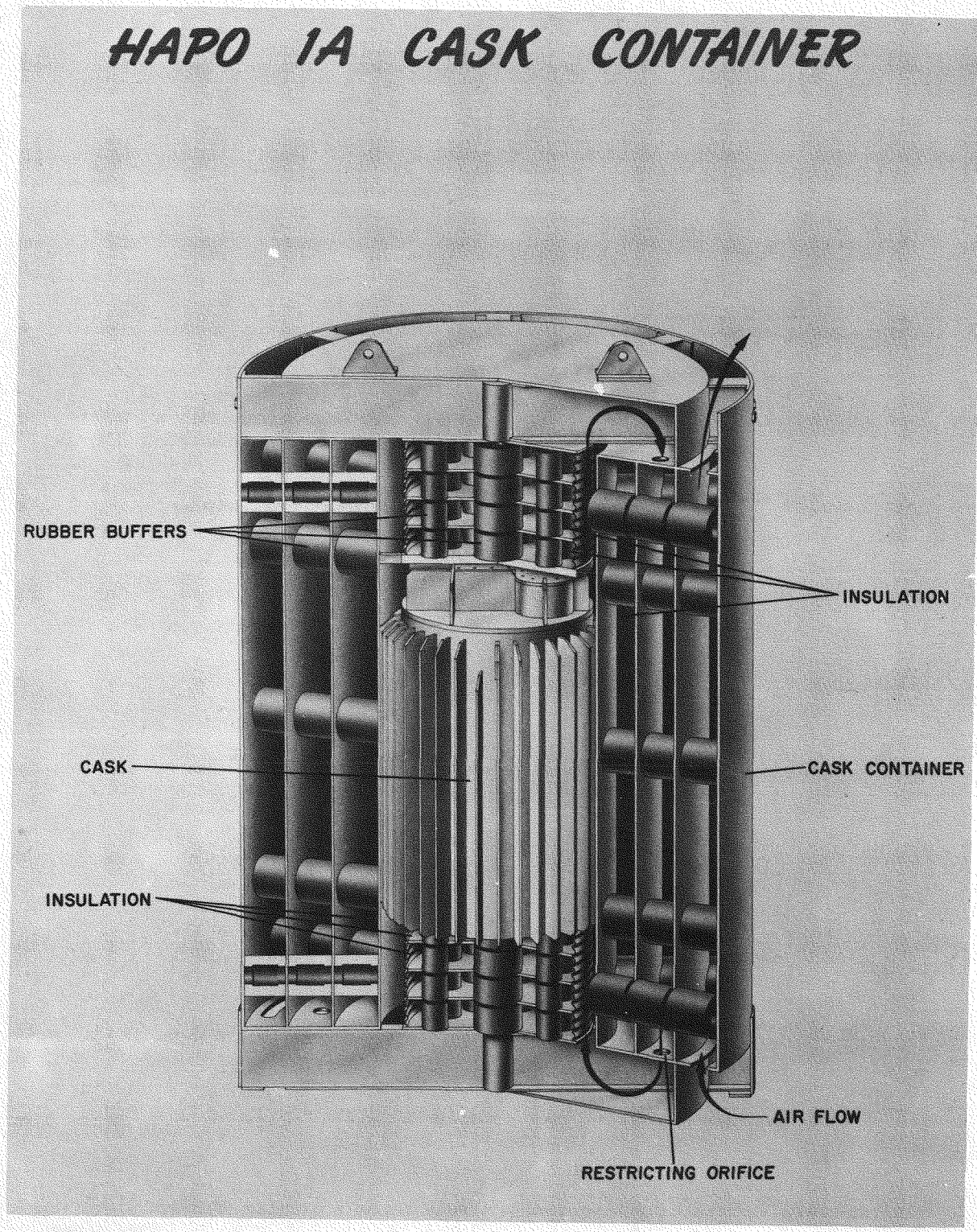
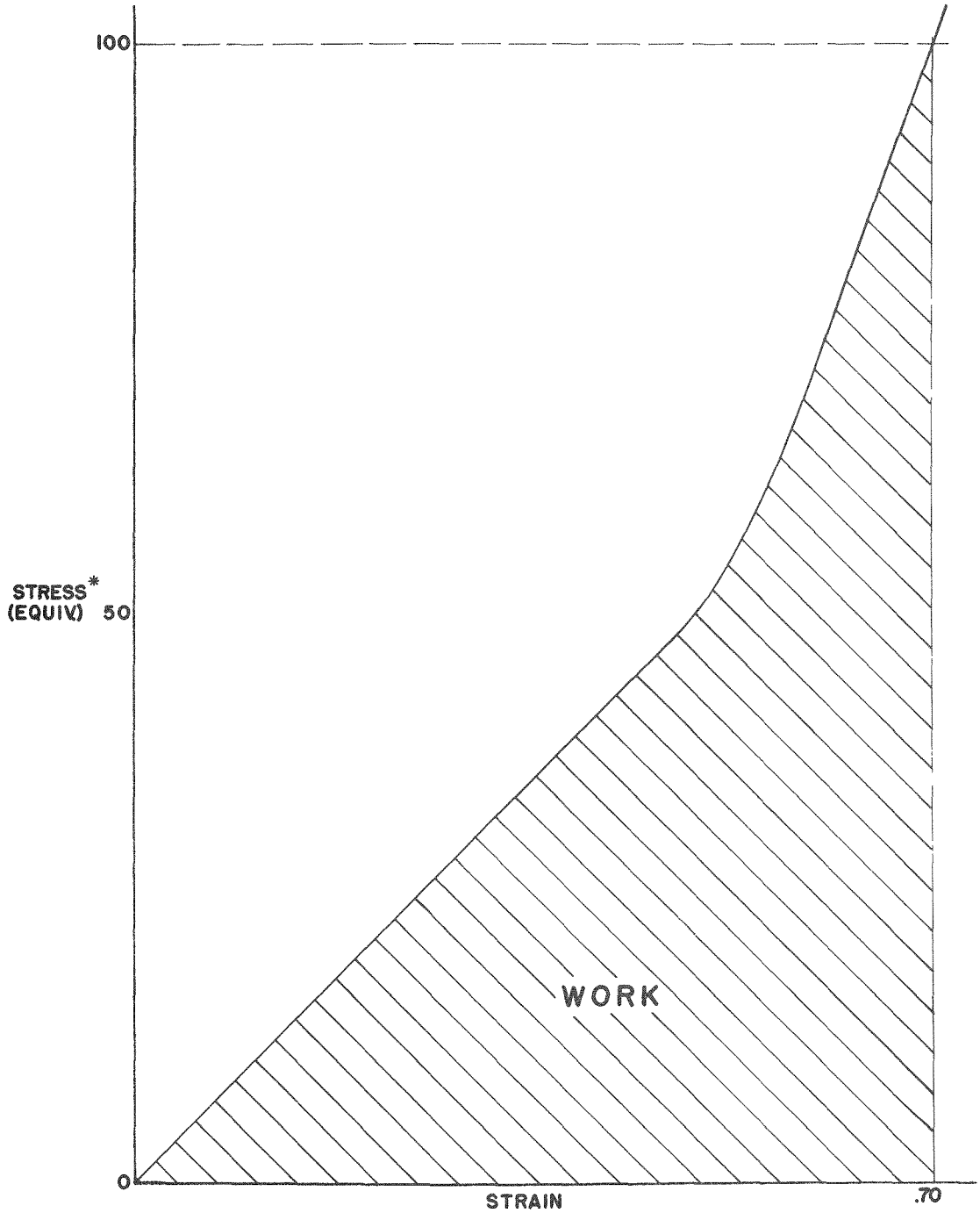

HAPO 1A CASK CONTAINER
RUBBER BUFFERS
INSULATION
CASK
CASK CONTAINER
INSULATION
AIR FLOW
RESTRICTING ORIFICE

FIGURE 5



RUBBER COMPOUNDS

STRESS* — STRAIN RELATIONSHIP

*PERCENT ALLOWABLE FORCE TRANSMITTED TO CASK SURFACE

FIGURE 6

Stainless steel honeycomb would appear to be needlessly expensive, since operation at high temperature is not involved.

Honeycomb of light-gage aluminum, resin-bonded, is available over the strength range required, with crushing strengths of 300 to 1200 psi or even higher. Over a temperature range -20F to 200 F, the properties of the aluminum and of the bonding materials are substantially unaffected. Further, the modulus of elasticity does not change greatly in dynamic vs. statis compression. The stress-strain characteristic (in crushing) is much more favorable to the buffer application than that of rubber. For a given maximum permissible loading (psi transmitted by the buffer to the cask surface) the comparative stress-strain characteristics are as shown in Figure 7.

Since "area under the curve" represents energy absorption, it is evident that the aluminum honeycomb will absorb the same energy in less than 50% of the stopping distance required by the rubber. Hence the buffer using crushable aluminum honeycomb on a "one shot" basis can be much smaller radially and axially and 10,000 lbs. lighter in the case of the 20-ton HAPO-I cask, than the one using rubber, as shown in Figure 8.

Scale models of this smaller buffer, using the same model cask, are just now being studied in the current program of design analysis and drop testing. Results to date indicate that these reductions of size and weight are attainable, and that aluminum honeycomb may be applied to reduce the size and weight of new full-scale containers for existing and future casks, so that railroad cars of normal height may be used. The application, however, requires careful engineering attention and may require some further testing of honeycomb products as components. Further, the honeycomb, being rigid up to the crushing stress, does not in itself protect against the small, periodic, continuous vibrations which are encountered in over-the-road travel.

Aluminum honeycomb is produced in considerable quantities for the aircraft industry, as a lightweight spacer and stiffener between inner and outer shells or similar applications, usually at design loadings well below the crushing strength. It is available in various thicknesses of aluminum sheet, and in a range of cell sizes. Investigations of behavior during crushing have been reported by Sandia[1], also by the Space Technology Laboratory [2], and by the University of Texas [3]. However, the honeycomb products of the several fabricators may differ considerably in their abilities to withstand off-axis loads, a factor of considerable importance in impact-cushioning where the load may come from any of several directions.

The material must be applied with some factor of safety as regards the per cent compressive strain. As indicated in Figure 7, there is a point of compressive strain, usually between 70 and 80% of initial axial dimension, beyond which the honeycomb becomes almost a solid and any further compression is attainable only at excessively high loading.

If these factors are recognized in the specific design, the prospect of smaller cask containers is very encouraging. Thus means are available for meeting the major problems involving heat flow and protection from excessive impacts.

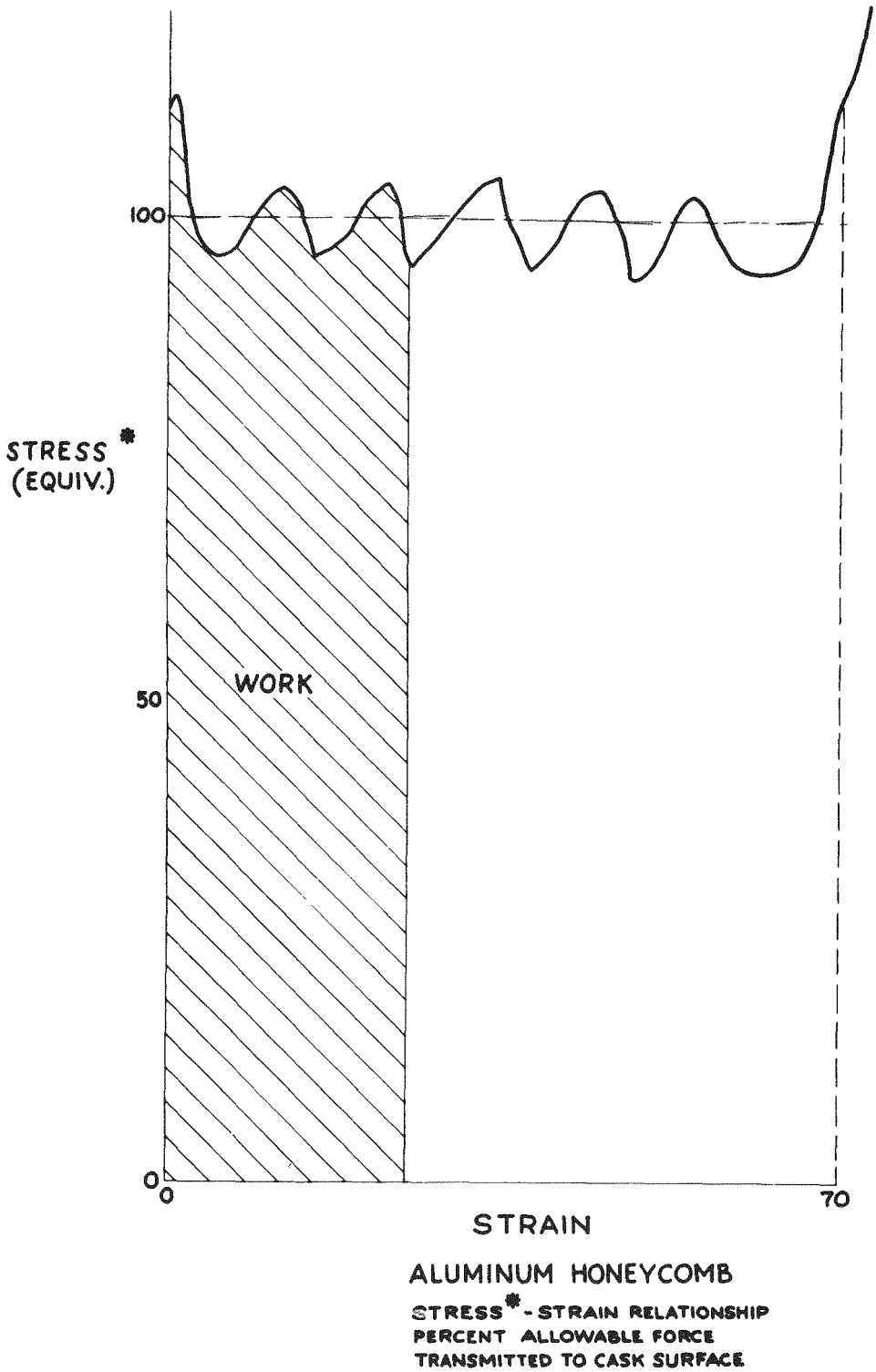

100
50
0
STRESS *
(EQUIV.)
WORK
0
70
STRAIN
ALUMINUM HONEYCOMB
STRESS* - STRAIN RELATIONSHIP
PERCENT ALLOWABLE FORCE
TRANSMITTED TO CASK SURFACE

FIGURE 7

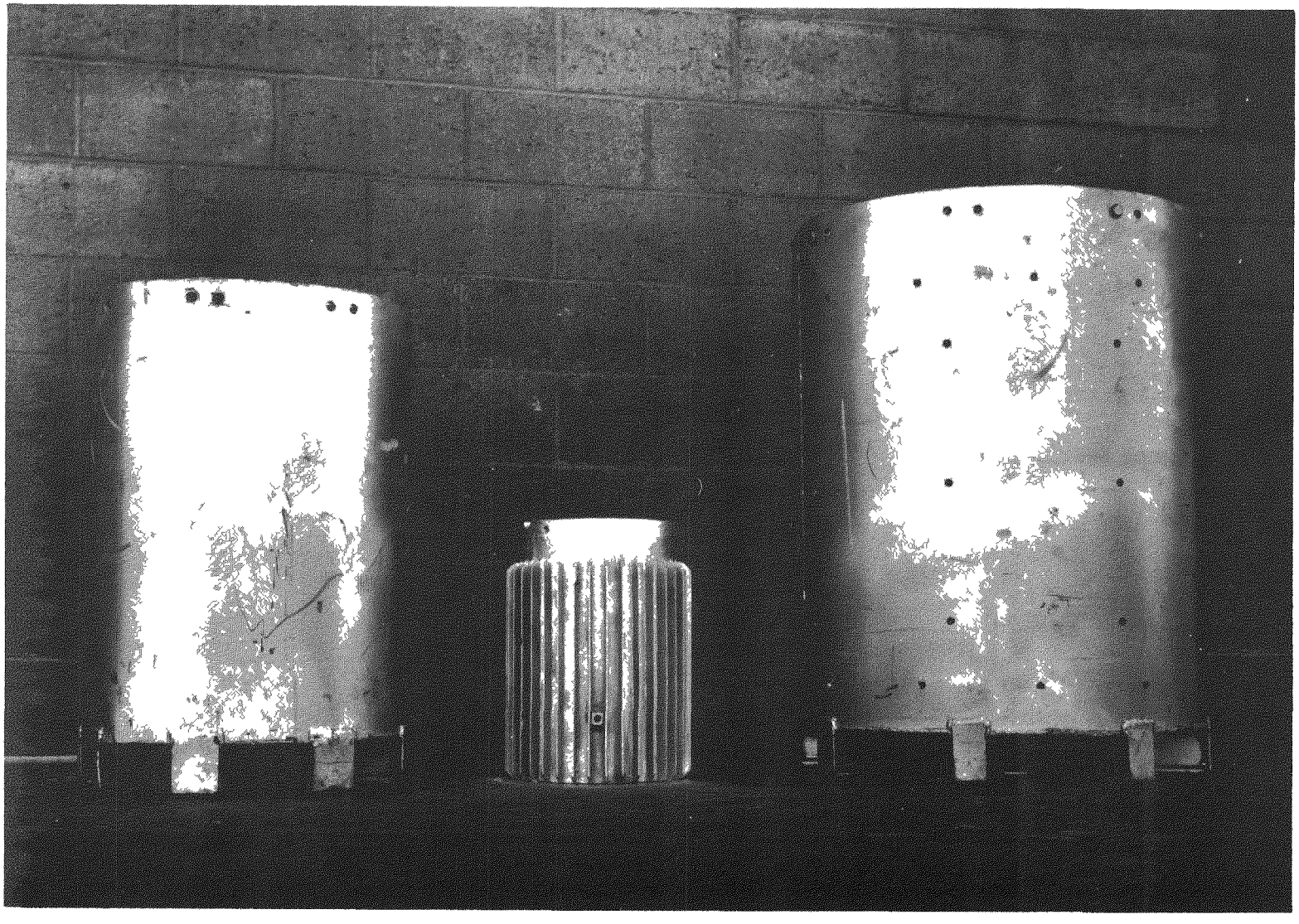


FIGURE 8

IV. DESIGN VERIFICATION TESTING

A lack of adequate engineering data applicable to certain aspects of the design, and the difficulty of making a complete analysis of the action of the buffering system during an impact has made it necessary as indicated previously, to rely on certain assumptions and estimates to complete the design. It is considered essential, therefore, that a program of proof testing be undertaken to determine directly, how well the buffering system and the shipping container meet the various design requirements.

The basic program objectives were the determination of the magnitudes of the three rectangular force components transmitted to the cask, and the observation of any damage to the cask as a result of striking a flat, relatively unyielding surface, or of striking certain defined surface irregularities, with a controlled impact attitude. In formulating the testing program criteria it was decided to concentrate on a free fall of 30 feet which produces an impact velocity of 44 feet per second. A few impacts at higher velocities were included in Phase I, however.

A. Scaling of Models

The size and cost of the prototype container virtually dictate the use of scaled-down models for a test program. A quarter scale model was selected because the quarter scale appears to be the greatest reduction feasible from the standpoint of metal thicknesses and sizes of welds. Similitude was preserved in the cask containers but the model casks were built to scale only as regards over-all size, weight, thickness of outer wall, length and thickness of the radial fins. Over-all criteria for scaling were:

a. To produce at the wall of the model cask the same unit loading which would have been produced by dropping the prototype.

b. To preserve the 30 ft free fall so that the initial impact velocity at the outer surface of the cask container would be the same for prototype or model.

The relationship between the acceleration of the model cask and the prototype cask can be simply derived from the following expression

$$a = \frac{F}{W}$$

where a is the acceleration in g's of the prototype cask, F is the force stopping the cask, and W is the weight of the cask. If it is assumed that F is proportional to the surface area of the cask

$$a = \frac{KA}{W}$$

The area of the model cask at 1/4 scale is

$$\frac{1}{16} A$$

and the weight is 1/64 W

Hence the acceleration of the model cask is

$$a' = \frac{4KA}{W}$$

or 4 times that of the prototype cask for the same surface loading as indicated by the constant K. Thus if the model tests produce an acceleration of 200g the prototype should show an acceleration of 50g, which is the design basis for the full sized prototype.

Since the stopping distance in the model is only 1/4 that in the prototype, the acceleration of the model cask must be 4 times that of the prototype if the impact velocity is the same for both.

If there are strain rate effects in the cushioning materials these effects will not be properly scaled in the model. In crushable materials such as aluminum honeycomb strain rate effects are negligible. In other materials such as rubber, where strain rate effects may not be negligible some allowance for the difference should be made in interpreting the results of model tests. However, the strain rates of the rubber in both the models and the full size prototypes are high enough to invoke the dynamic characteristics of the rubber compound.

B. Testing Facilities

Models were picked up on a quick release helicopter hook, hoisted to the required height by a winch, and then dropped. The impact surface is a steel armor plate 8-in. thick, case hardened on the top side.

This steel plate is tied down to a 24-in. thick reinforced concrete slab by a series of tie rods and wide flange steel beams. A very thin layer of grout was used to fill any voids between the concrete slab and the steel plate. The ratio of the mass of the steel and concrete impact surface to the total mass of model cask and shipping container is 30 to 1 for the rubber buffer container, and 32 to 1 for the aluminum honeycomb container. Additional resistance to any movement of the slab during impact is provided by the caliche on which the slab is founded. All things considered the steel slab and its support system meet the requirement of a "hard, unyielding surface."

The test facility, which is located at the University of Texas Structural Mechanics Research Laboratory is shown in Fig. 9.

C. Test Instrumentation

Three orthogonal components of acceleration were measured during each impact using three accelerometers mounted at or near the center of gravity of the cask model. Three accelerometers of the type and size shown in Fig. 10a were mounted in a triaxial mounting device as shown in Figs. 10b and 10c. This device which consists of an assemblage of machined pipes, plates, and angles welded together fits snugly into the cavity of the model cask as shown in Fig. 10d. The x and z accelerometers are oriented along the respective centroidal axes of the combined model cask and container assembly but the y accelerometer is mounted approximately 1-1/2 in. above its centroidal axis.

This triaxial mount when inserted into the cask cavity is firmly held transversely by set screws. The set screws near the top are internally mounted and tightened against the steel wall of the cavity. The set screws near the bottom are externally mounted as shown in Fig. 10d and are tightened against the machined wall of the triaxial holder. To complete the assembly a piece of asbestos fiber liner and the cask cover are tightened into position using four cap screws. Lead wires from the accelerometers are run out through a hole in the center of the cask cover, through a wide groove ground in the top edge of the

model cask, and then out through a hole cut in the buffer shells. This hole was always placed in the side opposite the impact, if possible, so as to minimize its effect of the action of the buffering system.

The three acceleration components were recorded as a function of time using a Minneapolis-Honeywell Visicorder. The relation of the coordinate axes to the various container attitudes at impact is shown in Fig. 11. Each accelerometer is mounted firmly to the triaxial mount using hexhead cap screws. In addition to acceleration measurements, high-speed motion pictures were taken during each drop to facilitate detailed study of the action of the buffering system during impact.

The accelerometers used were fluid damped at 70 percent of critical, had a natural frequency of about 1800 cps and a range of ± 500g. These accelerometers, because of the high damping, show no resonances and will overshoot on the application of a step acceleration only about 6 percent. The galvanometers in the Visicorder have natural frequencies of about 3000 cps and are damped at 64 percent of critical. Consequently they have essentially the same characteristics as the accelerometers.

D. Data Reduction

The velocity and the displacement of the cask during impact are obtained as functions of time by integrating the acceleration records. An analog computer is used to do the integrating and plotting. Acceleration time records as they come from the Visicorder are replotted to a larger scale on a Telereader.* The replotted curves are then traced with a conducting paint in order that they may be followed by an electronic curve follower. This curve follower reads the acceleration into the analog computer as a continuous function of time. Some rounding and smoothing of the acceleration record is produced as acceleration is read into the computer due to the inability of the curve follower to follow accurately, sudden changes in the record. This rounding is not considered to be serious and it compensates to some extent the overshoot of the accelerometers and the Visicorder. The effect of the rounding on velocity and displacement is quite small since the area involved is very small.

E. Instrumentation Calibration and Data Reduction Check

As a check on the reliability of the instrumentation and data reduction systems, an extensive series of preliminary development and calibration checks were made. Approximately 40 drops were made with unbuffered casks on various types of cushioning materials with known properties. Acceleration records were carefully studied and sources of potential error were systematically removed. Such procedures as the use of set screws to tighten the triaxial mount, addition of an asbestos fiber liner under the cask cover, etc., were developed in this stage.

The entire system was calibrated by dropping the cask and buffer assembly from a low height on paper honeycomb. A typical calibration drop acceleration record, along with the resulting velocity and displacement records are shown in Fig. 12. This record is for a free fall of 4 ft 6 in. onto 6 in. of paper honeycomb. The acceleration-time record was integrated twice on the analog computer and indicated a maximum displacement of the cask of 4.17 in. after impact. The



Fig. 9 Drop Facility at The University of Texas Structural Mechanics Research Laboratory

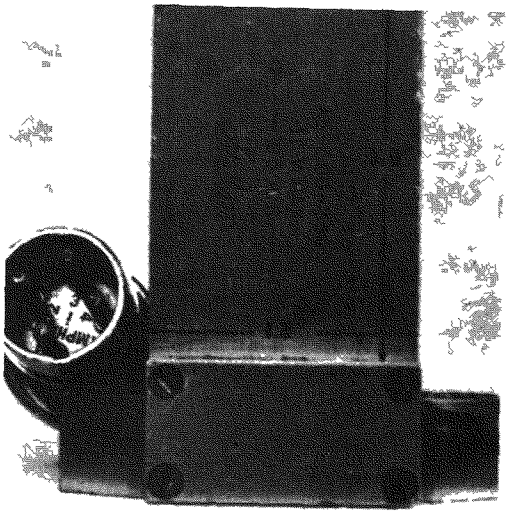


Fig 10a Accelerometer

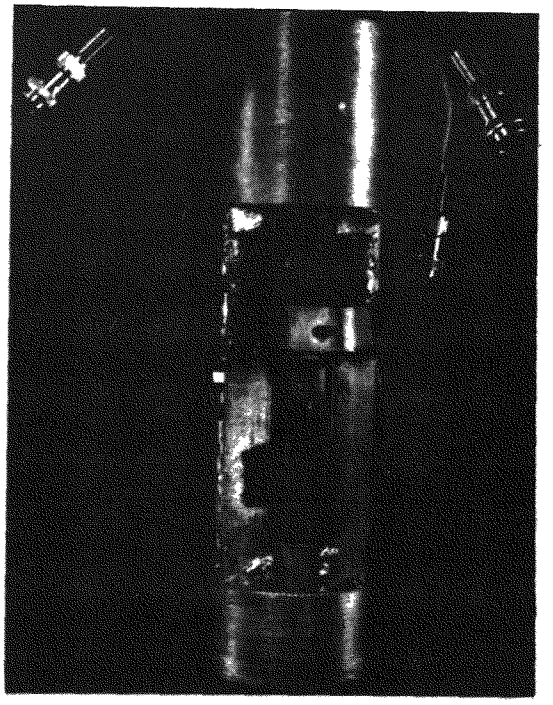


Fig. 10b Triaxial Accelerometer Mount
Two Accelerometers Visible



Fig. 10d. Placing the Accelerometer Mount in the Cask

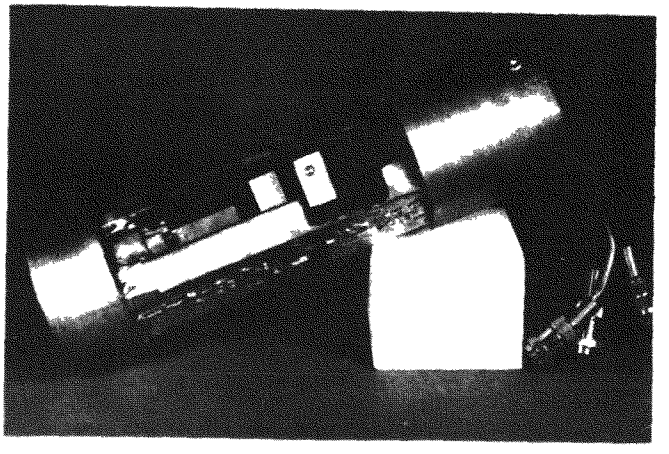


Fig. 10c. Triaxial Accelerometer Mount with All Three Accelerometers Visible

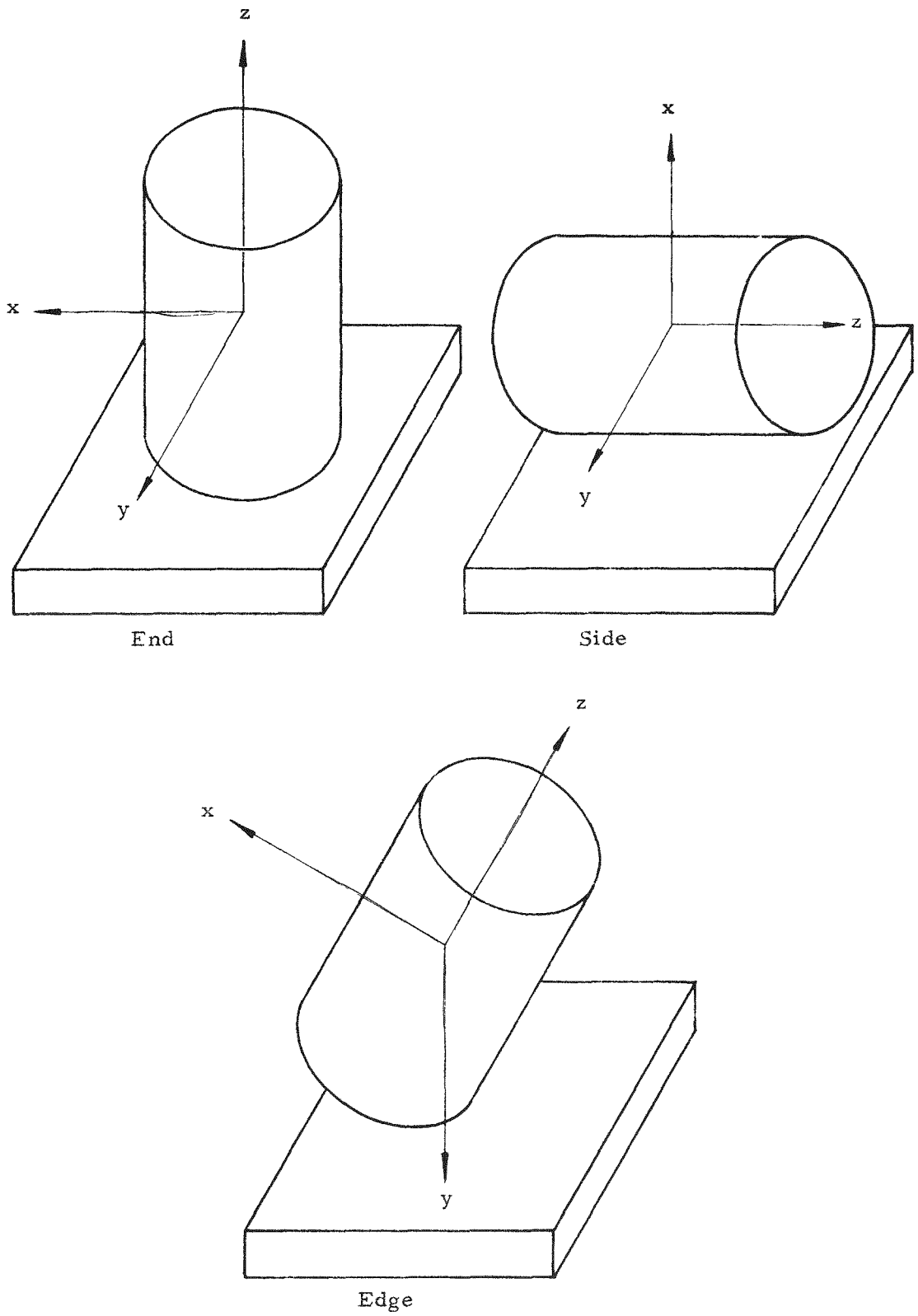


Fig. 11. Coordinate Axes and Container Attitudes.

measured crushing of the honeycomb sheets was a minimum of 4.0 in. after a slight rebound. Careful examination of the cask showed that no appreciable internal movement occurred within the buffer assembly.

F. Tests Performed

The actual testing consisted of 22 drop tests of rubber buffer shipping containers in Phase I, and 9 drop tests of aluminum honeycomb buffer shipping containers in Phase II. However, three of the tests in Phase I were nondestructive drops from low heights onto paper honeycomb cushioning material in order to provide instrumentation calibration. A summary of the 28 destructive drop tests is given in Table 1.

Table I. Types of Tests

Phase	Orientation	Height	No. of Test Drops
	End	30 ft	2
	Side	30 ft	7
I	Edge	30 ft	2
Rubber	Edge	40 ft	1
Buffers	Edge	55 ft	1
	End on Step Obstruction	30 ft	2
	Side on Step Obstruction	30 ft	2
	Side on Pin	30 ft	2
	Subtotals		19
II Aluminum Honeycomb	End	30 ft	2
	Side	30 ft	7
	Subtotals		9
	TOTALS		28

---

* Data plotting device made by Telecomputing Corporation

From this table it will be noted that the three different orientations used were the end, side, and edge with the center of gravity of the system directly above the point of impact. In addition two models were dropped in both the end and the side orientations onto an 8-in. steel step. For one set the edge of the obstruction was placed so that it made contact from one edge to the centerline, while in the other set it made contact from one edge to the quarter point. In a severe test of the shell's ability to withstand puncture, two models were dropped from 30 ft in the side orientation onto a blunt pin 1-1/2 in. in diameter and 4-in. high. This pin represents a 6-in. diameter object on the scale of the prototype container.

G. Test Results

Rubber Buffer Models

The general characteristics of the models with rubber buffer elements may be seen in Fig. 13a which is an overhead view looking along the

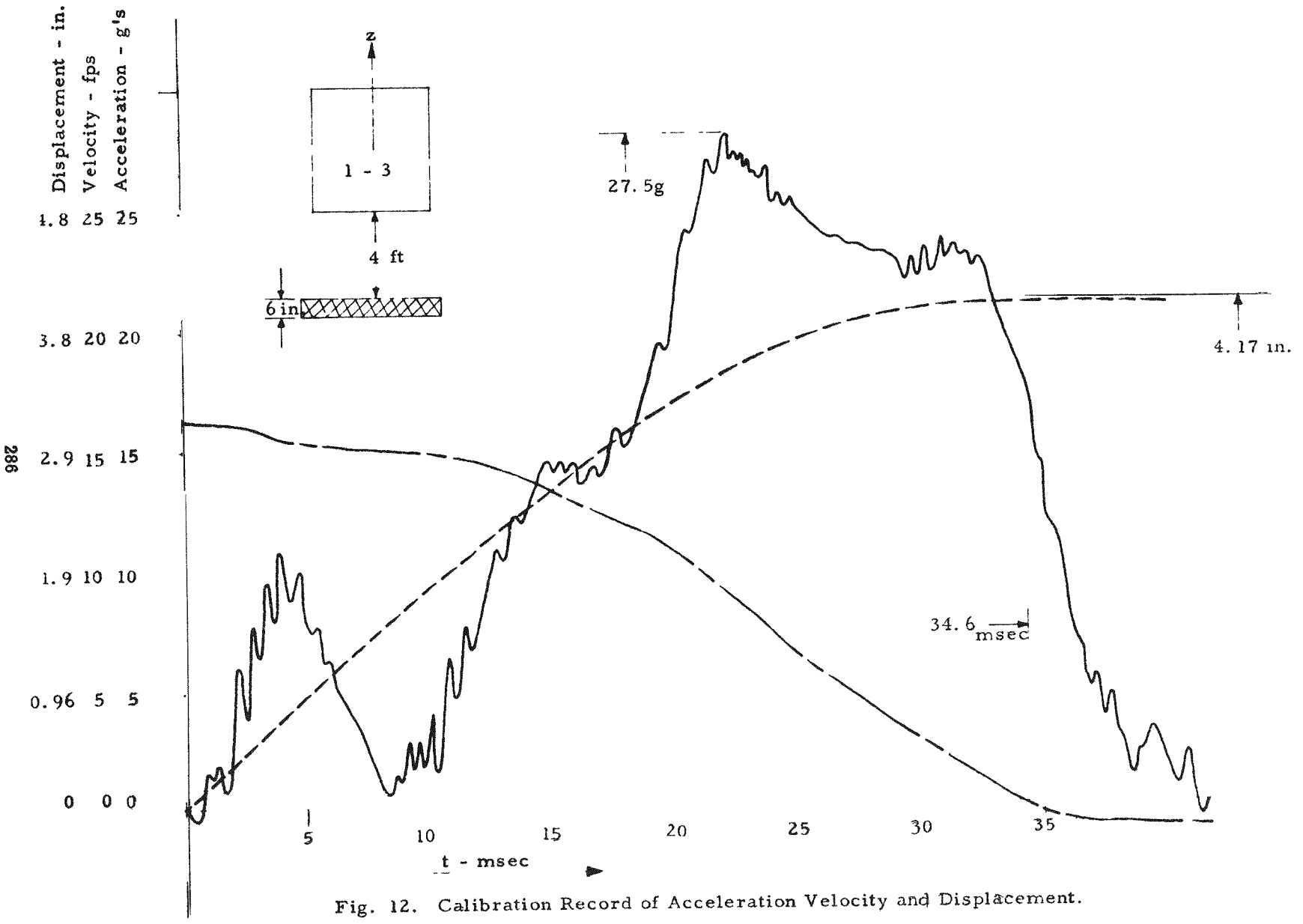


Fig. 12. Calibration Record of Acceleration Velocity and Displacement.

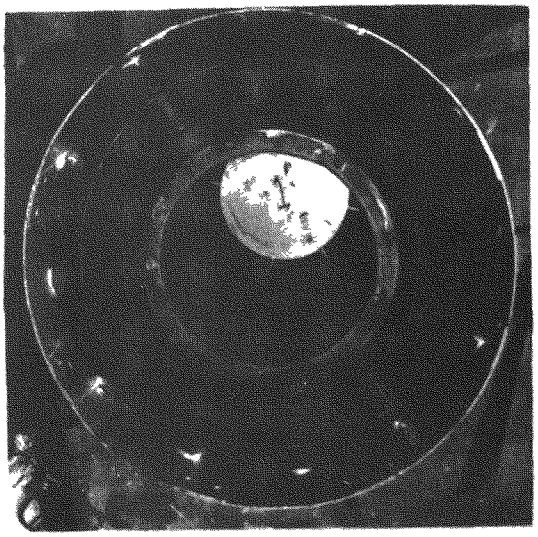


Fig 13a. View Along the Axis of a Rubber Buffer Model

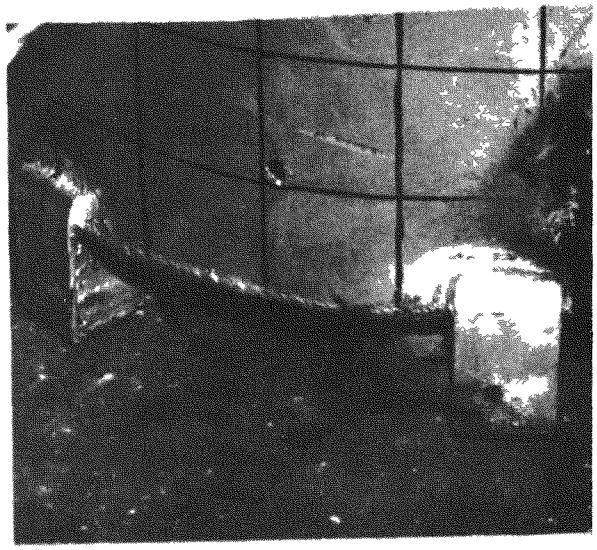


Fig 13b. Damage Produced in the Outer Wall by an End Drop

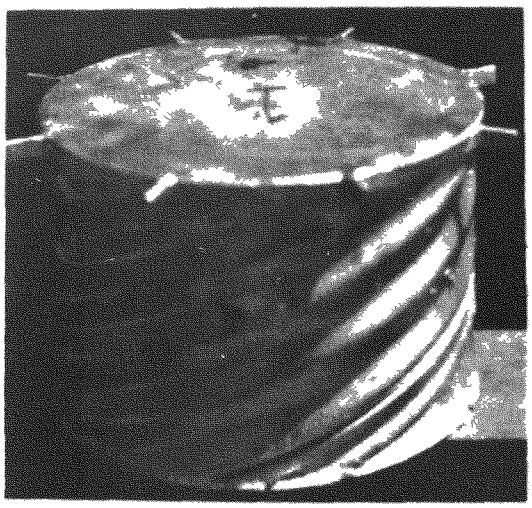


Fig. 13c. The End Buffer Assembly Before an End Drop

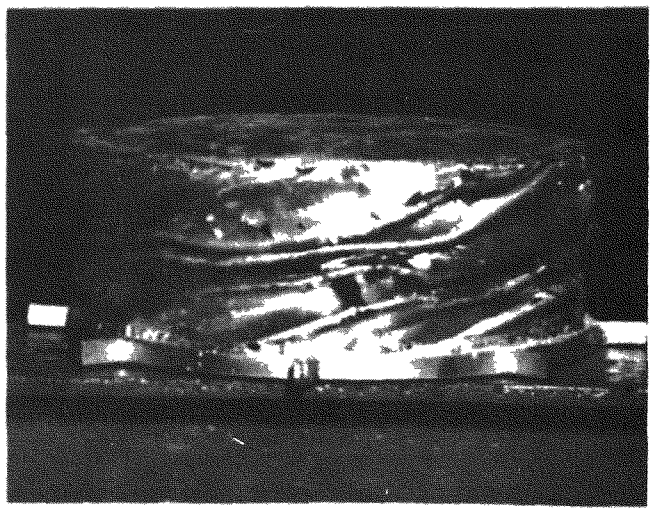


Fig 13d. The End Buffer Assembly After an End Drop

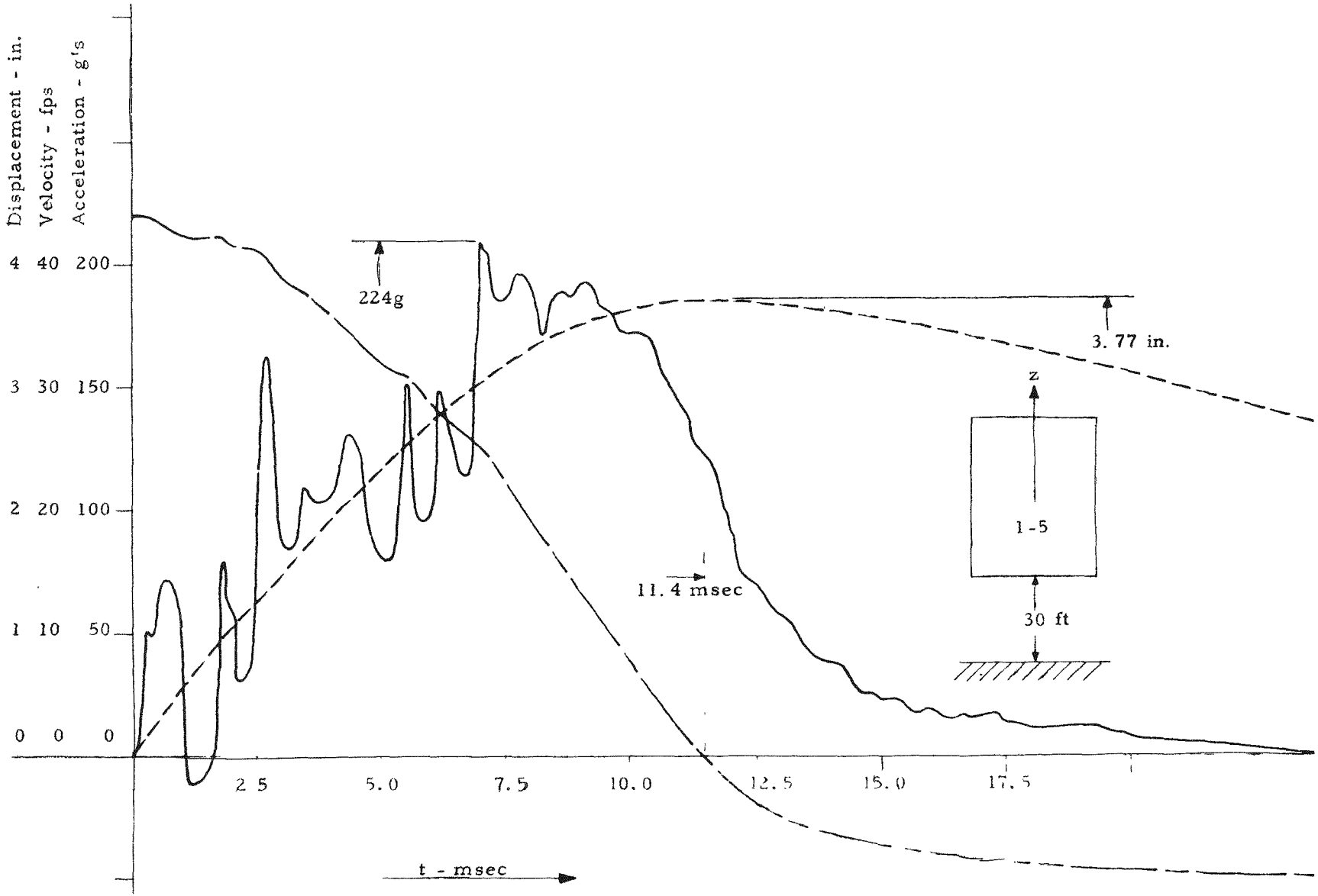


Fig. 14. Acceleration Velocity and Displacement Records for an End Drop of a Rubber Buffer Model.

container z axis. The three rows of rubber buffer elements and the four concentric shells are readily visible. The disk marked 1 is the top of the bottom buffer unit on which the cask rests during normal transit.

End Drops

Damage was in general rather light in the end drops. The only noticeable damage done to the shells was a slight buckling in the outer shell directly above the beams in the end spiders as illustrated in Fig. 13b. The end buffer was severely crushed as illustrated in Figs. 13c and 13d. These buffers must crush, of course, to perform their intended function.

A measured acceleration record, along with computed velocity and displacement records for the cask in an end drop from 30 feet are shown in Fig. 14. The maximum computed displacement is 3.84 inch. The measured permanent deformation of the end buffer was approximately 3.5 inch. Note that the maximum peak acceleration is 190 g. The design acceleration for the models is 200 g.

Side Drops

The acceleration, velocity, and displacement records for a 30 ft side drop are shown in Fig. 15. The acceleration record indicates a much greater variability than in the end drop. Undoubtedly much of this is caused by the exceedingly complex interaction of the steel shell and rubber buffer elements in their deformation after impact. The maximum peak acceleration indicated is 222g, but all of the acceleration peaks above 220g's have very short durations.

Damage to the container was more extensive and widespread than in the end drops. Bending and deformations of the shells can be readily seen in Fig. 16a which is a picture of the end of the container with the lid removed. Extensive buckling of the interior shell was also noted as shown in Fig. 16b. This is a view looking directly down the inner annulus of the container. The inner shell "wrinkle" apex coincides with the impact axis and occurs below the level of the cask radial fins. Some fin marks on the shell wall are also apparent.

Edge Drops

The cask and container combination were dropped in a special configuration arranged so that a vertical line through the center of gravity of the entire assembly passed through the lower edge of the container. Figure 17 illustrates this configuration, and is somewhat remarkable in that it also illustrates the final position of the container after a 30 ft free fall. The spider assembly at the point of impact deformed appreciably and furnished a sufficiently wide bearing area so that the container came to final rest in the edge position. The components of the acceleration in the x and z directions are shown in Fig. 18. Note that the peak accelerations along these two axes did not occur simultaneously. However, even if they had, the resultant acceleration would be less than the 200g design acceleration.

Damage to the container was not extensive, being fairly well confined to severe buckling of the webs of the end spider members at the point of impact, and to an uneven compression of the bottom buffer assembly.

Edge drops were also made with 40 ft and 55 ft free falls. As in the drops from 30 ft, damage was not very severe. Most damage occurred

to the end spider members, the lower edges of the exterior shells, and the bottom buffer assembly. It is extremely noteworthy that the resultant maximum acceleration in these drops is not appreciably greater than the maximum observed for the 30 ft fall. These records are also in good agreement with the magnitude of damage observed, and are encouraging in that they indicate the possibility of providing energy dissipation systems for even greater ranges of impact velocity.

Special Surface Irregularities

To further extend the range of information obtained, drop tests were performed with special surface irregularities replacing the flat impact surface used in the preceding tests. This test series included: 1) Side drops on 1-1/2 in. diameter pin. Two drops were made from 30 ft onto a steel pin with 1-1/2 in. diameter and 4-in. height. In both cases the pin penetrated the container shells as shown in Figs. 19a and 19b. The 4-in. pin penetrated through the four shells, bent aside the fins, and embedded itself about 1/2 in. into the cask. This extremely severe test indicates that a relatively small amount of energy is dissipated as the pin pierces each shell. 2) End and side drops on a step obstruction. Containers were dropped from 30 ft above an 8-in. steel step set on the steel impact slab. In one series of an end and a side drop, the container was oriented so that one half of the ordinary impact area hit the step. No appreciable difference was noted in the end drop from the ordinary end drop. The main difference in the side drop was in the nature of deformation. As can be seen in Fig. 19c, the outer shells were severely bent with an appreciable crease forming along the position of the edge of the step. Internal load distribution was good and no unusual damage to the cask was noted. In a second series of drops on step type obstructions, the step was oriented so that contact was made along the quarter point of the model rather than at the centerline. This resulted in an extreme amount of rotational action of the containers, with the assemblies bounding off the step as shown in Fig. 19d. The substantial transformation of energy into rotational energy seems to reduce the damage in these impacts.

Summary - Rubber Buffers

A comparison of the measured peak accelerations with the design acceleration is shown in Fig. 20. It can be readily seen that neither the end drop nor the edge drop configurations were as severe as the side drops. Also, the rotational energy transfer in the obstruction tests indicates that they are not as severe a test of the buffers as the side drop. However, while the peak accelerations noted in the side drops are consistently above the 200g design value, the "smooth peak" values are below the design value. The results of the side drop of the 1-1/2 in. diameter pin indicate that this particular design of buffered container is vulnerable to penetration by sharp, stiff objects.

Aluminum Honeycomb Buffer Models

The general characteristics of the containers with aluminum honeycomb buffer elements may be seen in Figs. 21a and 21b. These are overhead views looking along the z axis of specimens which have been subjected to a side impact. In the model shown in Fig. 21a the aluminum pads have been lined up radially and in the model of Fig. 21b the pads are staggered so as not to line up radially. Figs. 21c and 21d illustrate the arrangement of the honeycomb pads in along the

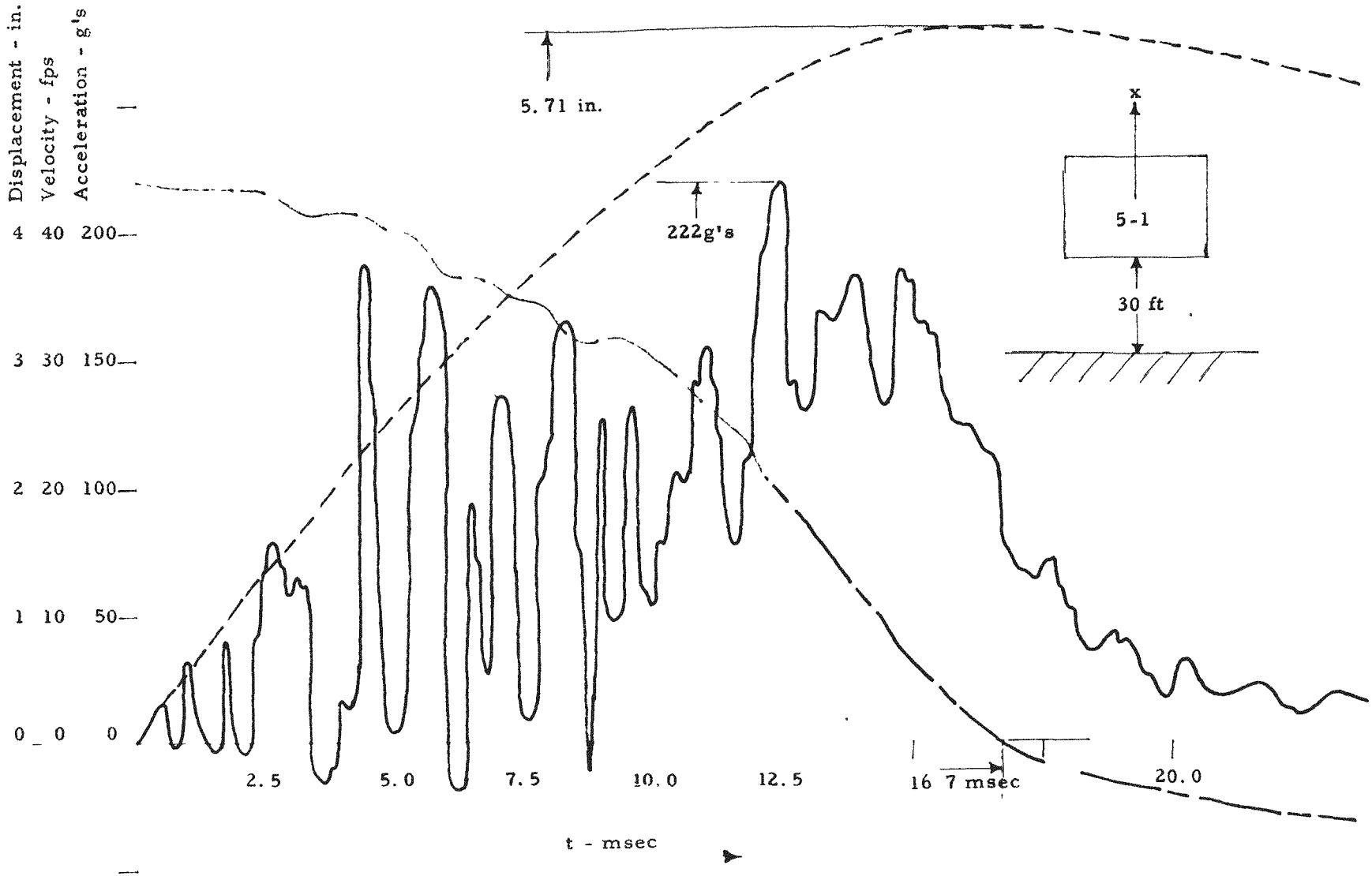


Fig. 15. Acceleration, Velocity and Displacement Records for a Side Drop of a Rubber Buffer Model.

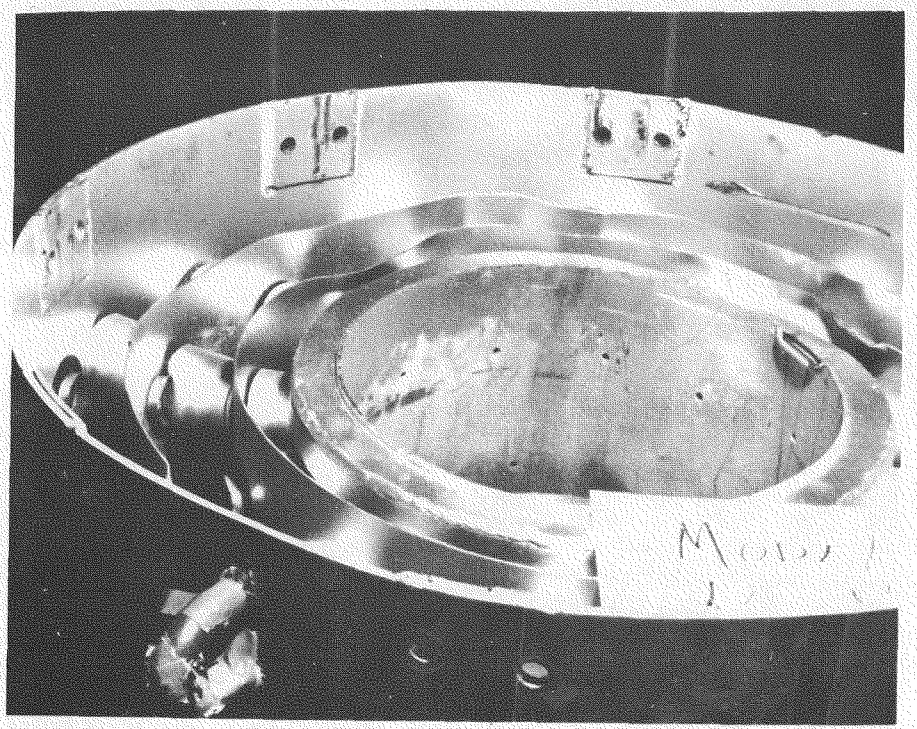


Fig. 16a. Damage Produced in a Rubber Buffer Model by a Side Drop

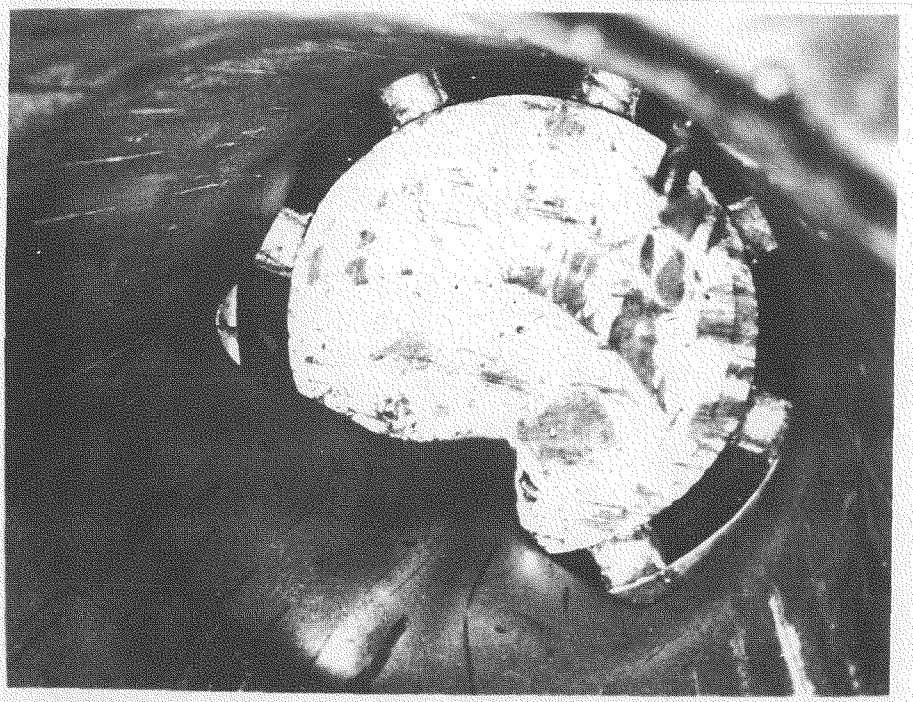


Fig. 16b. An Interior View of Damage Produced in a Rubber Buffer Model by a Side Drop. Note the Marks Made by the Fins on the Cask



Fig. 17 An Edge Drop of a Rubber Buffer Model

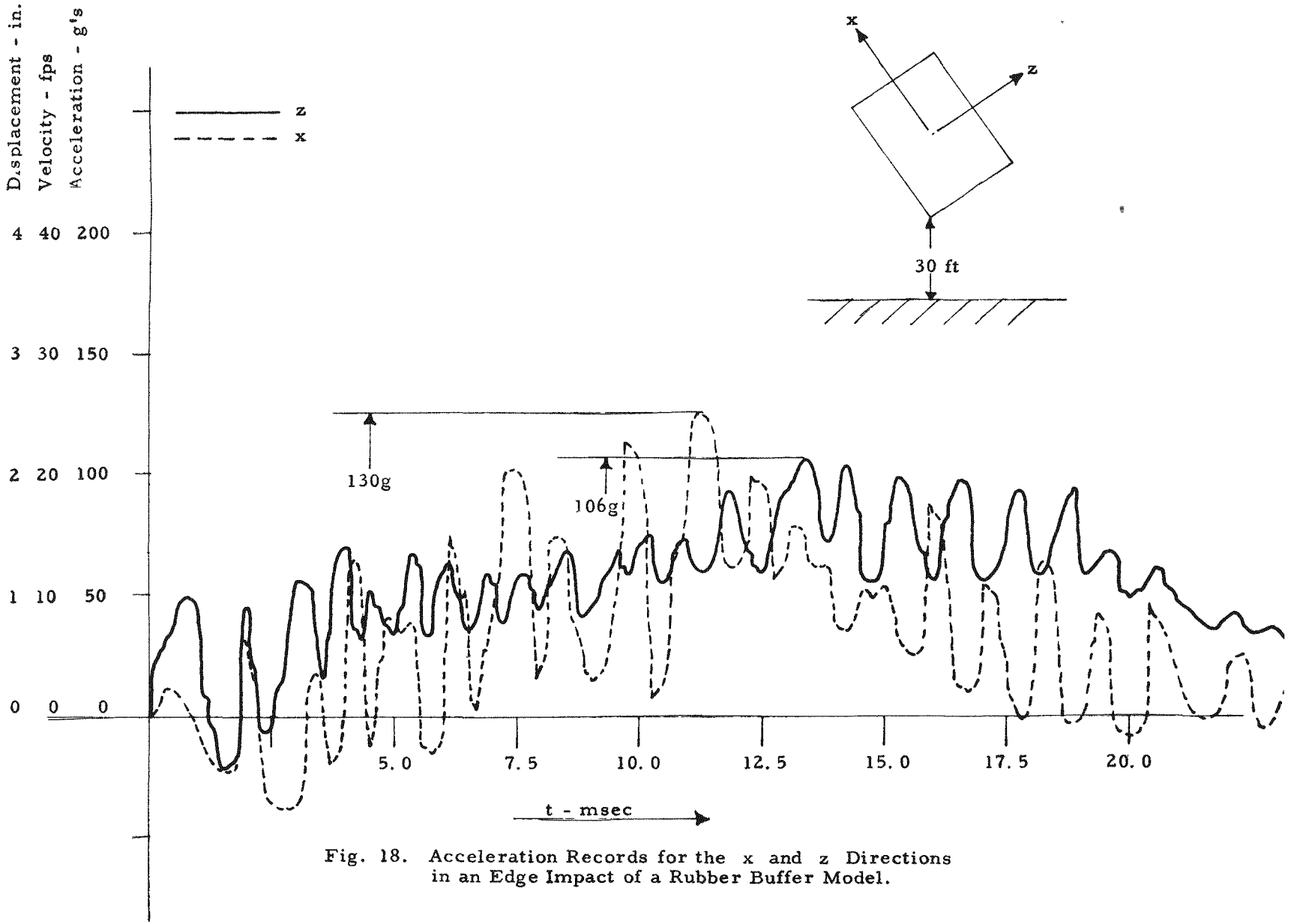


Fig. 18. Acceleration Records for the x and z Directions in an Edge Impact of a Rubber Buffer Model.

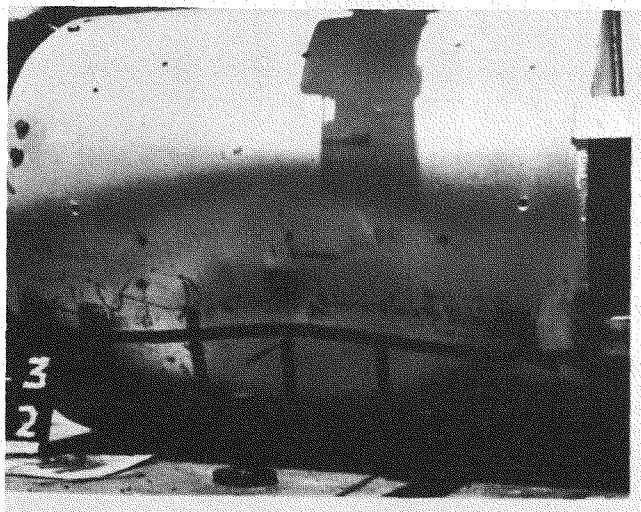


Fig. 19a. Exterior View of the Damage Produced by a Side Drop on a Pin

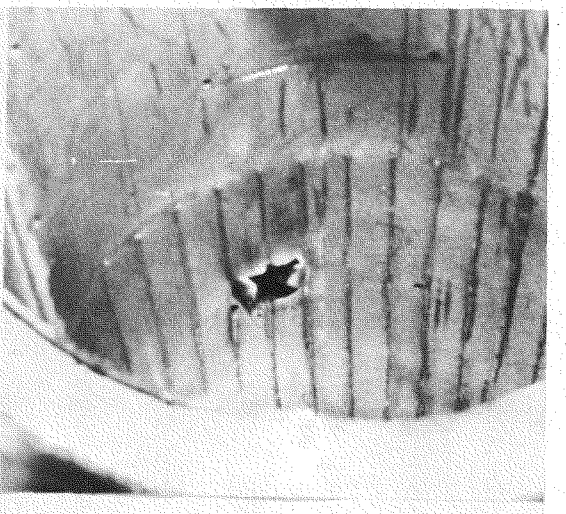


Fig. 19b. Interior View of the Damage Done by the Pin

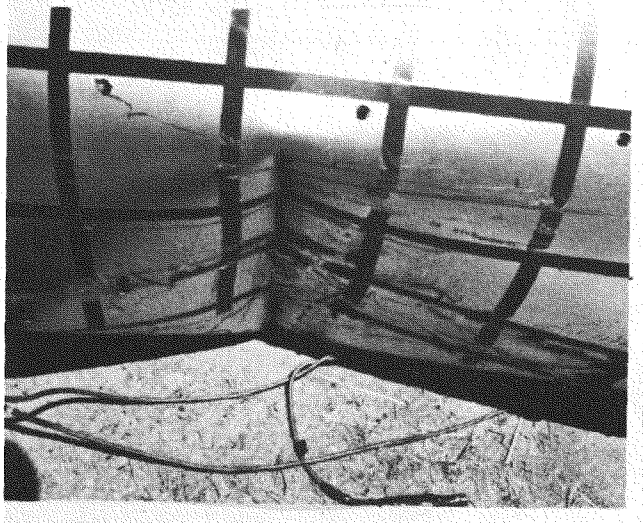


Fig. 19c. Exterior View of the Damage Produced by Impact on a Step Obstruction

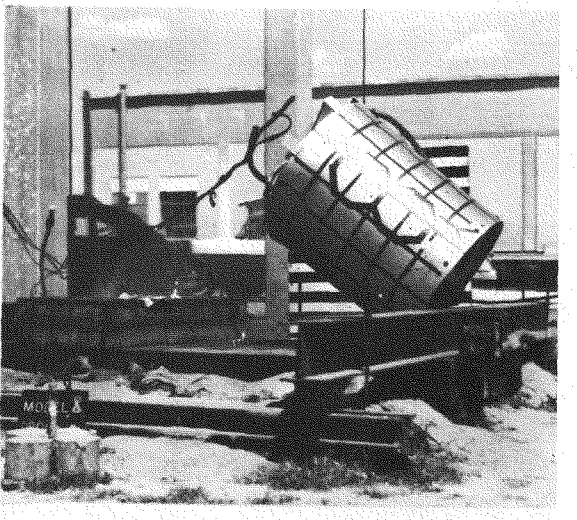


Fig. 19d. Container Rebounding After End Impact on the Step Obstruction at the Left

shells. Also these photos illustrate typical crushing of the honeycomb during a side impact when configurations of the type shown are used.

End Drops

The acceleration record for an end drop from a 30 ft height is shown in Fig. 22. A peak acceleration of 300g was reached in this drop but the peak of a "smoothed" acceleration would be much less than 200g. A slight reduction in the crushing strength of the honeycomb cushion would reduce the acceleration and at the same time provide sufficient energy dissipation without any increase in the volume of the honeycomb being required. Approximately 60 percent of the available honeycomb was crushed in this drop. The violent fluctuations in the magnitude of the acceleration was apparently caused by stress waves propagating through the cask rather than by big changes occurring in the stopping force.

Side Drops

In the initial side drops very little crushing of the aluminum honeycomb was observed and the recorded accelerations showed peaks as high as 530g. Detailed re-examination and re-appraisal of the design computations and determination of the actual crushing strength of the material indicated that a greater area of stronger material was being brought into play then was contemplated in the original calculations. The remaining containers were then altered by removal of a portion of the aluminum honeycomb material as shown in Fig. 21c. Originally the rows were filled the entire length of the shell. Approximately 50 percent of the original material has been removed for the configuration shown. The record obtained from a 30 ft side drop with an altered cushioning configuration shown in Fig. 23. Again the peak acceleration is 530g but the "smooth peak" would be substantially less. The maximum displacement indicated was only 1.36 inch. Examination of the buffer elements of the middle ring indicated approximately 50 percent crushing in elements directly along the impact axis. Detailed examination also indicated pronounced "dimpling" of the shells and the possibility exists that some shells transferred partial load by direct contact. The remaining tests in the series explored the effects of various slight modifications in the buffering arrangement. Accelerations were reduced somewhat and more uniform crushing of the honeycomb was noted. However, the number of available models in this series was exhausted before a positive evaluation could be completed.

Summary - Aluminum Honeycomb Buffers

A comparison of the measured aluminum honeycomb buffer peak accelerations with the design acceleration is shown in Fig. 24. It can be seen that the end drop is very close to being acceptable. It appears that only a slight reduction in the crushing strength of the aluminum honeycomb will be required to hold the peak acceleration to the design value in the end drops. However, the side drop records indicate that further study of the cushioning design is required. All tests give an average acceleration substantially higher than the 200g design acceleration. This seems to be the result of a distribution of the load over a greater area of the cushioning material than was anticipated in the original design. The distribution pattern has been indicated by the results of this test program so it should be possible now to redesign the containers to achieve the required degree of cushioning.

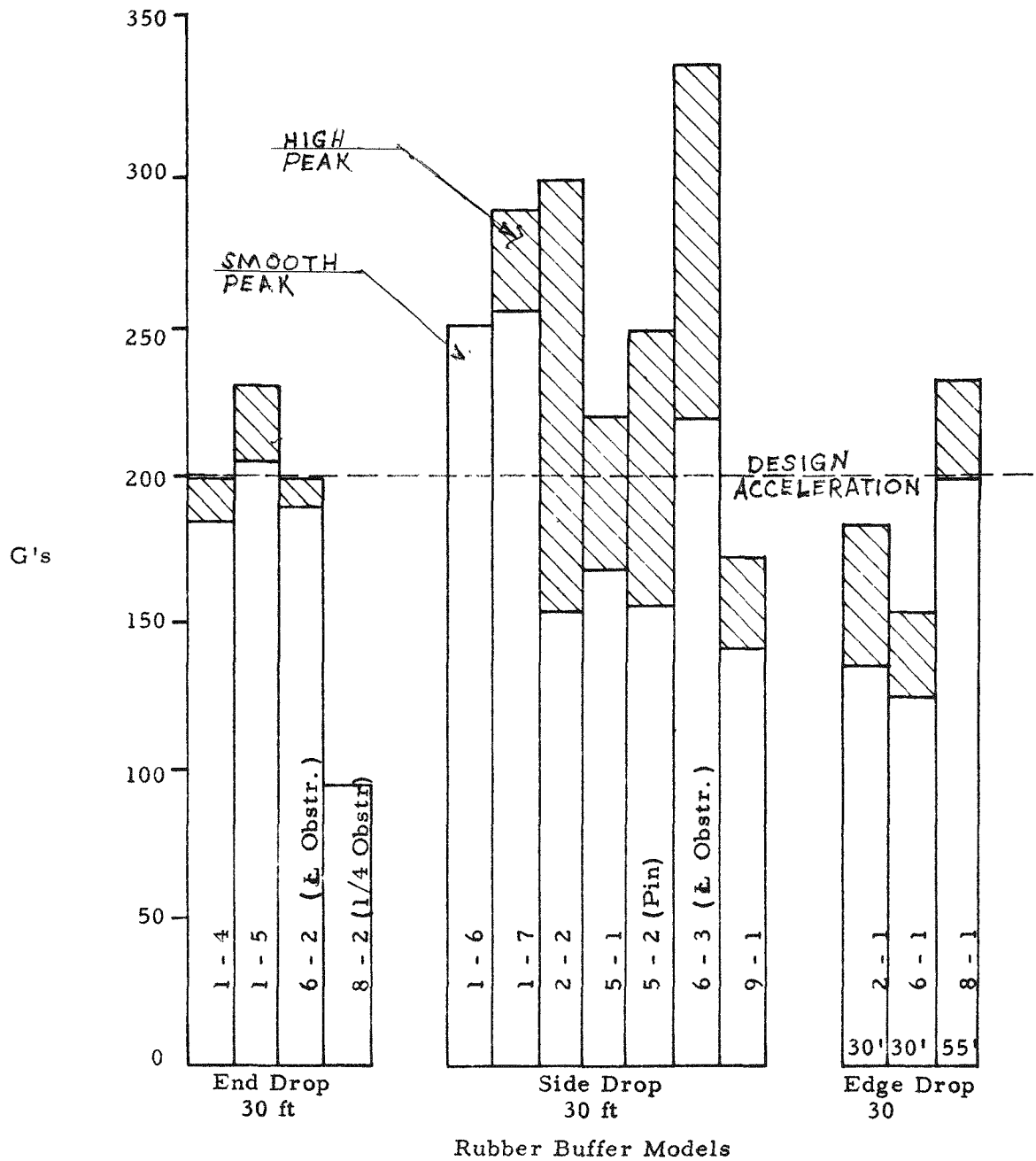


Fig. 20. Comparison of Measured Peak Acceleration and the Design Acceleration for Rubber Buffer Models.

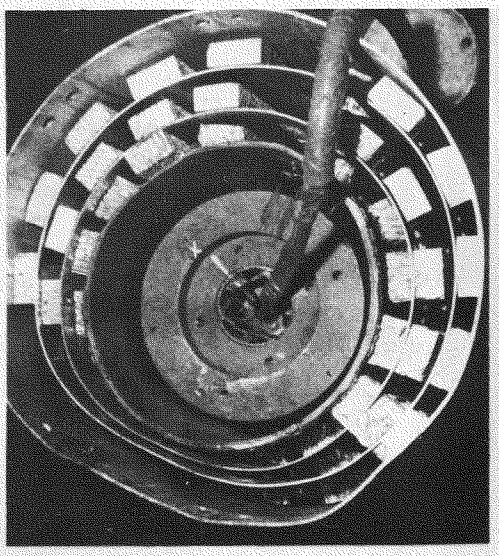


Fig. 21a. Deformation of Buffering Shells After a Side Impact with the Cushioning Pads Lined Up Radially

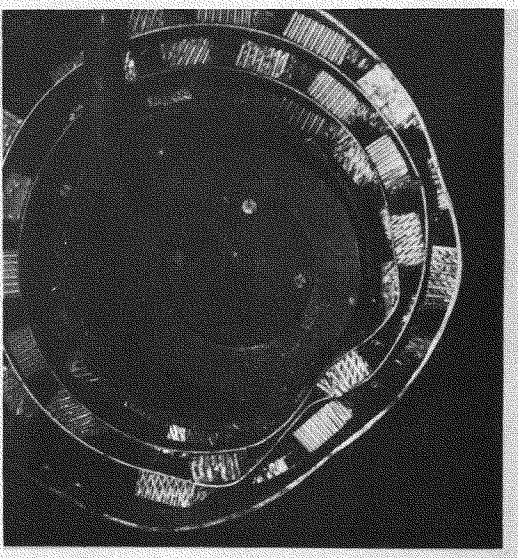


Fig. 21b. Deformation of the Buffering Shells as a Consequence of a Side Impact. Note the Staggered Arrangement of the Cushioning Pads

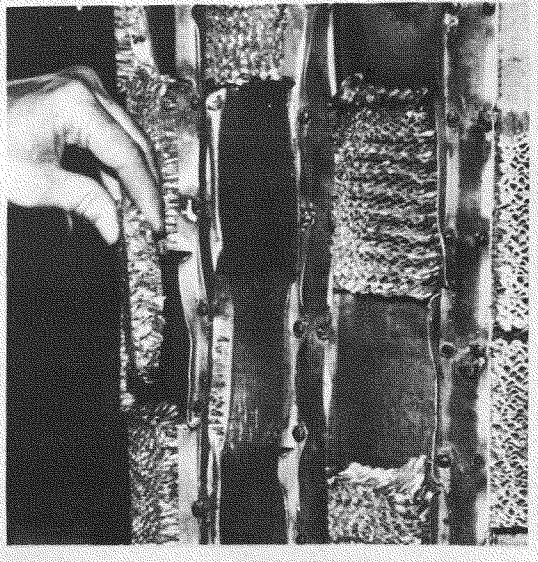


Fig. 21c. Aluminum Honeycomb Pads Crushed During a Side Impact

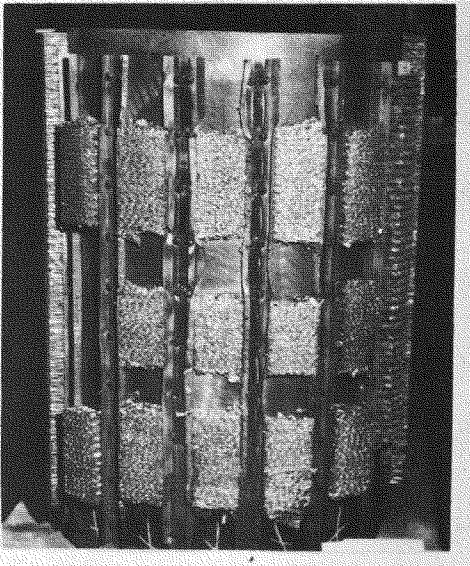


Fig. 21d. This View Shows the Extent of Crushing on Either Side of the Line of Impact Indicated by the Arrow. Cushioning Pads Were Lined Up Radially. This is the Innermost Layer of Cushioning

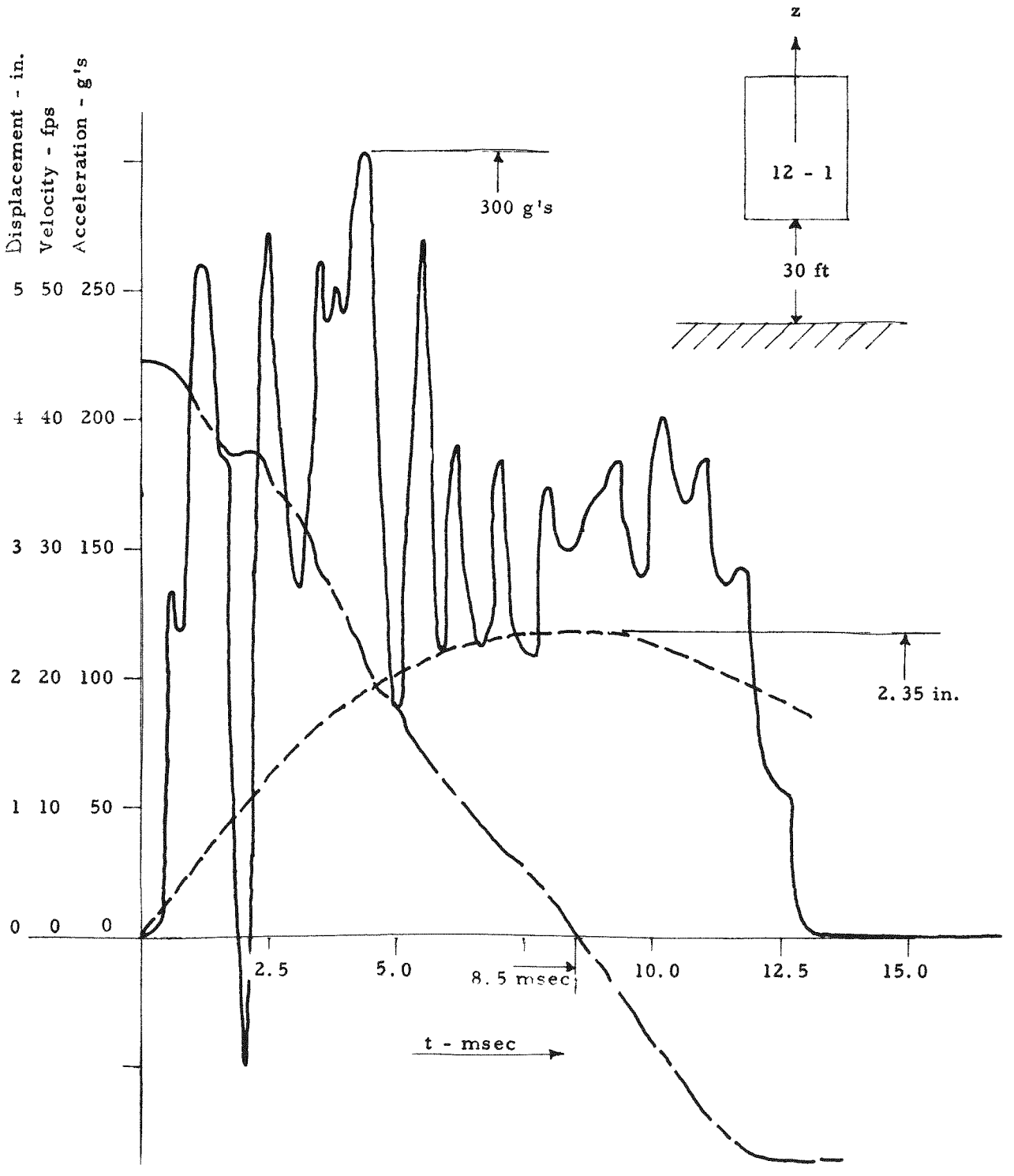


Fig. 22. Acceleration Record - End Drop
Aluminum Honeycomb Buffers

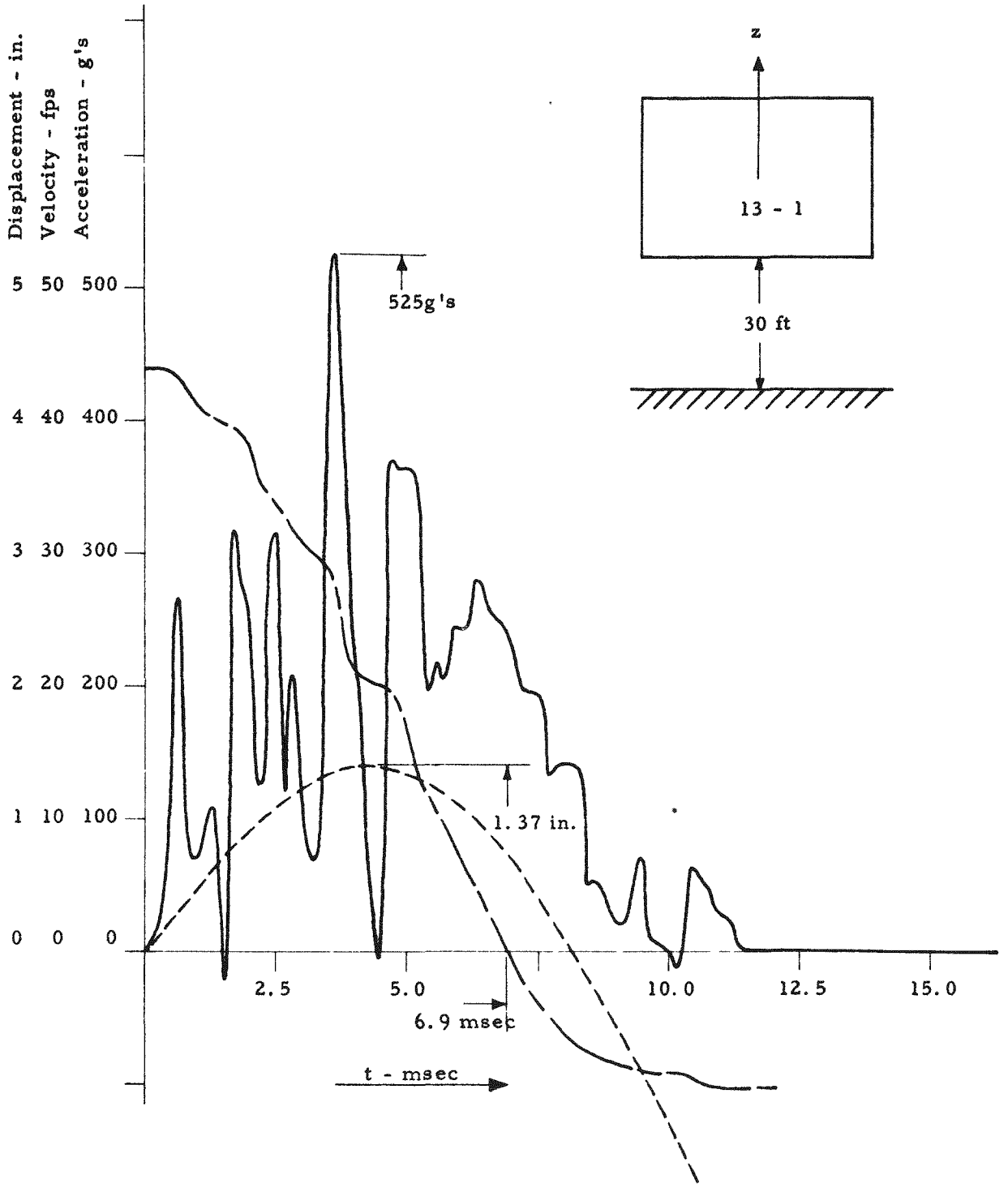


Fig. 23. Acceleration Record - Side Drop
Aluminum Honeycomb Buffers

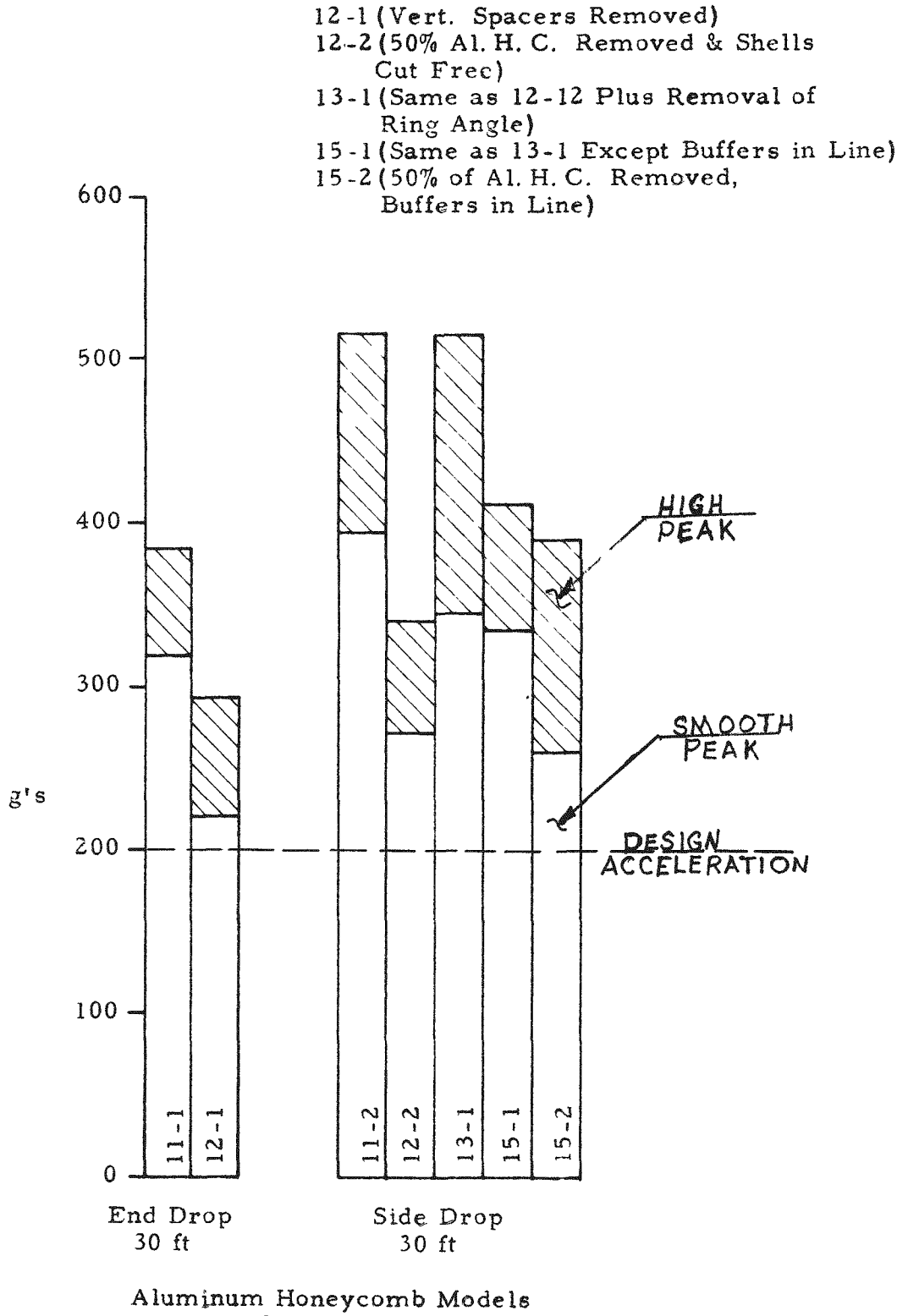


Fig. 24. Comparison of Measured Peak Accelerations and the Design Acceleration for Aluminum Honeycomb Buffer Models

The model casks used in these tests suffered no damage as a result of the impacts. To check the stress developed in the walls of the cask, the cask was stress-coated for some of the drops. No cracks were developed in the stress coat as a result of the drops; however, light tapping of one of the fins with a rawhide mallet produced a great profusion of cracks in the stress coat.

V. SUMMARY

In summary, the cask containers provide a method for predicting the forces imposed on a cask for almost any drop height and any impact attitude. Thus it is possible to predict the damage to the cask itself which will occur as a result of specified impact conditions. In addition, the cask container provides considerable flexibility in meeting requirements regarding resistance to fire and in handling capabilities at the shipping and receiving site since the cask itself does not have to withstand impact with an unyielding surface. The continued use of cask containers for impact protection will result in substantial size, weight, and cost reduction and in improvements in energy absorbing capabilities.

VI. REFERENCES

1. "Energy-Absorbing Characteristics of Several Materials," Sandia Technical Memorandum S.C.T.M. 284-57(51) by V. Parfitt.

2. "Characteristics of Energy-Absorbing Materials for a Lunar Soft-Landing Vehicle," by M. Feigen, D. Fitzgibbon, E. Burchman, Space Technology Laboratories, Inc.

3. "Energy-Dissipating Characteristics of Trussgrid Aluminum Honeycomb," by J. M. Lewallen and E. A. Ripperger, University of Texas.

Session Chairman: Yesterday we heard Larry Shappert describe an impact testing program at Oak Ridge National Laboratory. Another group at the Oak Ridge National Laboratory in an associated project is concerned with the shipments of isotopes, primarily, sealed sources, and have been running a series of fire tests both at Oak Ridge and the Underwriters' Fire Laboratories.

Mr. Leonard Horn, Associate Managing Engineer of the Underwriters' Laboratories, will describe the tests performed by their Laboratories.

FIRE TESTING OF RADIOISOTOPE SHIPPING CONTAINERS AND COBALT 60 TELETHERAPY HEAD

LEONARD HORN, UNDERWRITERS' LABORATORIES, INC.,
CHICAGO, ILLINOIS

INTRODUCTION:

For many years, the effect of a serious fire upon a radioisotope shipping container stored in a warehouse that burned down or transported in a truck which became enveloped in a gasoline fire following an accident on the highway, has been the subject of speculation and conjecture. While it may be possible to calculate the end result of such fire exposure, the number and character of the variables involved in the calculation are exceedingly complex and the calculations are apt to go far astray from the actual facts.

In March, 1960 the Atomic Energy Commission issued for public comment a proposed regulation to establish general criteria for the design of shipping containers for irradiated fuel elements and to establish shipping requirements to protect against accidental criticality and radiation exposure in the shipment of these components. This proposal requires that a shipping container shall be able to withstand exposure to a standard 1-hr fire test without emission of radiation in excess of one roentgen per hour one meter from the container surface. The proposal identifies a standard 1 hr fire as exposure for 1 hr to a fire in which the

following temperatures are reached at various times after the beginning of the fire:

1000 F after 5 min

1300 F after 10 min

1550 F after 30 min

1700 F after 1 hr

This test was developed by Underwriters' Laboratories, Inc., for the evaluation of fire resistance of building materials, record storage containers, safes, etc., and is described in specifications of the National Fire Protection Association (NFPA No. 251) and the American Society for Testing Materials (ASTM, Design E119-50).

The AEC Division of Isotopes Development has considered application of this test to shipping containers for radioisotopes, and in June, 1961, arranged for Underwriters' Laboratories, Inc. to perform a program of fire tests upon the following units:

1. Type 2R container, over-all dimensions approximately 2-3/16 in. diameter by 5-11/16 in. length.
2. Type 55 container, identified as ORNL No. 4C2.
3. Cobalt 60 teletherapy head, capacity approximately 1000 curies.

SERIES 1 TESTS

TEST METHOD:

(1) Samples were mounted in a test furnace for a period of one-half hour, with the furnace temperature adjusted to the Time-Temperature Curve shown in Fig. 1. At the end of one-half hour it was intended that the furnace should be shut down, the units allowed to cool and examined for cracks or other failure.

(2) It was then intended to subject the units to a 1-hr fire test with the furnace temperature again adjusted to follow the

Time-Temperature Curve. After the 1-hr exposure, the furnace was to be shut down, the samples quickly removed, and cooled by application of a standard fire hose stream for a period of 1 min.

(3) If the samples were still intact following the two preceding tests, it was intended to repeat the 1-hr test, quickly remove the samples from the furnace while still heated, and drop them from a height of 30 ft upon a brick-rubble pad.

TEST RESULTS:

Series No. 1 tests terminated abruptly during the initial 1/2 hr exposure by "explosion" of the Type 55 container. After approximately 15 min, and at a furnace air temperature of approximately 1320 F adjacent the container, the central portion of the container, including the plug, the top flange, and most of the lead shielding, were violently separated from the body and hurled against the furnace ceiling. No visible damage had occurred to the Type 2R container or the teletherapy head.

Further study established that moisture had been trapped in the annular expansion space at the bottom of the shipping container. This moisture had flashed to steam, the pressure had ruptured the welded joint between the top flange and the jacket, and had ejected the central bulk of the container. The Oak Ridge National Laboratory, who control the use and transport of these containers, is now following a regular procedure of drying out, under a vacuum pumping and heating cycle, each of these units after shipment to reduce the possibility of repeating in the field the accident which occurred in our test furnace.

In view of this unexpected result, the first series of tests was terminated without carrying to a conclusion the complete series of tests which has been outlined.

SERIES 2 TESTS

TEST METHOD:

A new, simple, inexpensive test furnace was constructed at our Northbrook, Ill. Testing Station and separate tests were conducted on a Type 55 shipping container, and the teletherapy head used in the first test. Facilities were not available to lift the devices for the drop test originally scheduled at the end of the investigation, and this test was eliminated from the schedule.

The Oak Ridge National Laboratory provided a new dried-out Type 55 sample for the test while the teletherapy head which had not been damaged by the previous 15-min test was again employed. Tests (1) and (2) of the original program were repeated and after each 1-hr fire test, the units were cooled by 1 min application of a standard fire hose stream.

TEST RESULTS:

TYPE 55 CONTAINER

1/2-HR TEST: (Test No. 2)

The following temperatures were recorded at the end of the 1/2-hr test:

Surface of container - 1445 F at 17 min.

Air expansion space above leads shielding - 1225 F at 30 min.

Air temperature above source - 700 F at 45 min.

Lead shielding - 675 F at 30 min.

A maximum internal pressure of 95 psi was recorded approximately 26 min after the start of the test.

After approximately 13 min, a small opening appeared in the top of the container and small amounts of lead were noted to be oozing through this hole.

1-HR TEST: (Test No. 3)

The following maximum temperatures were recorded throughout and after the test:

Surface of container - 1950 F at 48 min.

Air expansion space above lead shielding - 1760 F at 60 min.

Air temperature above source - 1560 F at 50 min.

Lead shielding - 1560 F at 50 min.

Internal pressures within the container could not be determined due to solidification of lead within the pressure line, as a result of the 1/2-hr test.

26 min after the start of the test, it was noted that lead was issuing from one of the thermocouple fittings provided in the container. After 41 min a sizable crack developed in the top of the container at a portion of the circular welded joint between the container top and the cylindrical side wall, and molten lead began to issue from the crack.

The application of the hose stream, at the conclusion of the test, did not appear to affect the unit materially. At the conclusion of the test, it was found that the crack in the weld was approximately 5 in. long and 1/16 in. wide at the widest part, and it was determined that approximately 15 lb of lead had been emitted through the crack and the thermocouple fitting.

At the conclusion of the test, the container was cut in half, through its axis, to observe the internal distribution of lead shielding.

TELETHERAPY HEAD

1/2-HR TEST: (Test No. 4)

To provide an indication of the temperatures attained within the space for the Cobalt 60 source, a small ceramic pallet, hold-

ing eight ceramic temperature cones, was substituted for the source. The close fit of the shutter mechanism precluded the use of thermocouples for this temperature determination. The cones had a minimum temperature rating of 1238 F and a maximum rating of 1670 F.

After 22 min, a small pinhole developed in the upper section of the spherical steel shell and a small flame was observed at this pinhole. At 29 min, molten lead issued from this hole and the lead ceased flowing at 33 min. Approximately 14-3/4 lb of lead issued from this opening.

At the end of the test, the shutter was still operable, and examination of the temperature cones showed no bending. This indicated that the temperature in the space normally occupied by the source did not attain 1238 F during this test.

1-HR TEST: (Test No. 5)

To prevent further leakage through the pinhole in the steel shell, the opening was drilled and welded shut.

After approximately 14 min, a small crack was noted in the bottom of the flat face of the unit to which a collimator is normally secured. Molten lead was noted to be flowing from this crack. The stream of molten lead increased and continued to flow from this crack throughout the test. At 43 min, it was noted that molten lead was flowing from the shutter opening. At about 60 min, the flow of lead from the shutter opening ceased but the flow of lead from the crack in the collimator face continued.

At 65 min the furnace was shut down and the front wall was opened for the hose stream application. No material changes occurred during the hose stream application; however, the steady

flow of molten metal from the crack in the collimator face continued.

73 min after the start of the test, lead was still flowing from the unit and attempts were made to open the shutter. However, the shutter was found to be frozen in position. One hour and 45 min after the start of the test the molten lead ceased to flow from the assembly.

At the conclusion of the test, it was determined that the head lost approximately 839 lb of its lead shielding.

At the conclusion of the test, the unit was cut in half at approximately the center line of the shutter assembly, to observe the internal distribution of the lead shielding and attempt the recovery of the ceramic cones. The cone pallets and cones were broken in the removal, but it was found that none of the cones showed any signs of sag or bend, indicating that the temperature at the source did not exceed 1238 F during the test.

CONCLUSIONS

Of the three units tested, only the small Type 2R container, constructed entirely of stainless steel, withstood the test. However, this unit was subjected only to the 15-min exposure which terminated the Series 1 test program. The remaining two devices either lost large amounts of lead shielding as a result of the 1-hr exposure, or developed cracks in their steel shells at such locations that they would have lost their shielding had they been inverted or tipped to such a position that the rupture was at the lowest level.

RECOMMENDATIONS

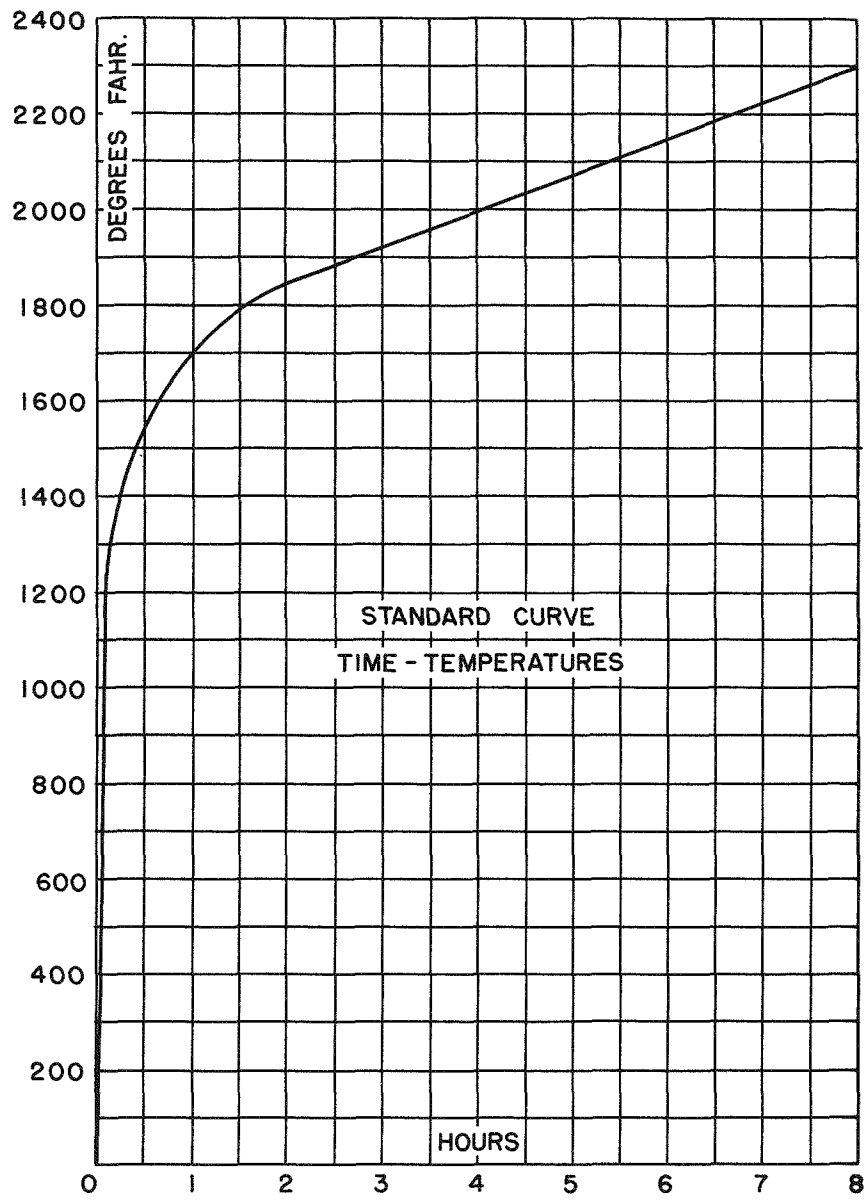
As a result of these tests, it is recommended that if lead shielding is employed in the construction of a shipping cask or container, suitable thermal barriers, shields, or other material

be provided to enable the unit to withstand the 1-hr fire test. These barriers or shields should also be of sufficient strength and so arranged as to withstand the 15-ft free fall and the puncture type of accident described in Section 72.32 of Proposed Regulation 10CFR Part 72 without destroying the thermal effectiveness of the shielding or protection. The internal construction of such units should be solid metal with no voids, to prevent the internal accumulation of moisture in hollow spaces, unless the thermal shielding is sufficient to limit the temperature of such trapped water below the vaporization temperature during the 1-hr fire exposure test.

It is recommended that, wherever possible, lead be eliminated as a shielding material and other materials be substituted which will not melt, vaporize, or be otherwise affected by the temperatures developed in a 1-hr fire test.

A report covering this work will be available through usual Office of Technical Service, U. S. Department of Commerce channels about January 31, 1963 under the category UC-23, Isotopes - Industrial Technology, TID-4500 (17th Edition), No. COO-274.

	TIME MIN.	DEG. FAHR.
	5	1000
	10	1300
	15	1400
	20	1460
	25	1510
	30	1550
	35	1580
	40	1610
	45	1640
	50	1660
	55	1680
1 HR.	60	1700
	75	1750
	90	1790
	105	1820
2 HRS.	120	1850
	150	1890
3 HRS.	180	1925
	210	1960
4 HRS.	240	2000
	270	2035
5 HRS.	300	2075
	330	2110
6 HRS.	360	2150
	390	2187
7 HRS.	420	2225
	450	2262
8 HRS.	480	2300



DISCUSSION AND COMMENTS

A question was raised as to the applicability of the standard one-hour fire test to large shipping casks. The standard one-hour fire or two-hour fire, whichever it may be in a particular case, was developed to represent conditions that might be expected for objects in a burning building; that is, objects such as a safe. Will a cask on a highway or on a railroad enveloped in petroleum flames, for example, to be subjected to these same conditions, or might we expect something substantially different?

In reply Mr. Horn indicated Underwriters' Laboratories have simply been called upon to test something for a one-hour test. We have tried not to be too positive as to whether this is the proper test or not. Nevertheless, there are times when a small shipping container, such as a Type 55, may be stored in a warehouse which might become involved in a fire. Then one could expect the time-temperature conditions corresponding, let's say, to a one-hour fire. In the case of large shipping containers, in which the hazard is fundamentally in transport, some of the things that I have seen and heard would indicate that the fire temperature may go up faster than a standard time-temperature curve, and it may be it might not be quite as hot.

But we have not been able to find any reports or any tests or any investigations made upon burning tank trucks or that sort of thing to evaluate this or to establish what the time-temperature conditions are. We don't know. All we know is that there have been a number of gasoline tanker accidents, and some of them, if they happen near an overhead steel structure, for example, have heat enough to quite seriously damage an overhead bridge. This has occurred, so they develop fairly healthy temperatures. The matter deserves further study.

In adjusting the furnace to follow the standard time temperature curve the flames are adjusted to follow the curve. Usually the furnace is calibrated with no object. If a large object is placed in the furnace, like a cask, further adjustments to the flame may be needed.

The amount of fuel, and maybe even the temperature of the flame, in order to follow the standard curve, is dependent upon what object is being tested, and maybe the larger object it is that is being tested, the larger amount of gas has to be used to follow the curve.

This adds complications to the problem of developing suitable data in order to calculate temperatures of such things as casks because the type of flame depends upon the type of object. It is a standard time temperature relationship, but not really a standard fire.

We have observed that when lead melts, it may attain a temperature of 1,000 degrees Fahrenheit or so. The expansion is of the order of 10 percent compared with its volumetric temperature. We might expect that upon subsequent cooling, we would find voids to the extent of some 10 percent; that is, the shell of the cask would expand and when the lead cools we would find substantial voids. In the section of the cask that you tested, I noticed that there was a void at the top of the lead, but this appeared to be of the order of only one or two percent of the lead volume and nowhere near 10 percent.

The only explanation is that some of that space was taken up by a void that was down underneath the source cavity. If you will notice in that section, the lead has not flowed back the way it should have been.

(UK Comment) We in the United Kingdom have also been looking for reasonably accurate reports of vehicle fires or transport fires generally, and we are in the same position as you. There is very little information. Reports of fires have appeared but it is very difficult to obtain information on temperature. Occasionally we have had reports that certain pieces of material, steel, aluminum, or glass were melted, but you cannot regard the melting of small portions of the structure involved as representing the mean effect of the temperature of the fire as whole. This is possibly due to local torching and effects of that kind. We have, however, had discussions with various people involved with transport, and we came to the conclusion that the standard time-temperature curve, although it may well be representative of building conditions, for which I think it was originally intended, is rather too high for a transport fire.

(UK Comment)
This is the reason that we have adopted 800 degrees Centigrade as a mean effective temperature. We will not go so far as to say that this is the final figure. If anybody can produce evidence to show that it should be some other more precise figure, we shall be very glad. We have found that this is a temperature to which we can control our furnaces very easily.

(UK Comment)
Having a lower temperature means a greater number of furnaces available. We also consider that it is satisfactory to use a constant temperature. My reason for doing this is that a building fire starts on a small scale and gradually builds up, whereas, a petroleum fire is really a vapor fire, which reaches full volume very rapidly. That, we feel, is justification for starting off at 800 degrees Centigrade.

(UK Comment)
A second point I would like to refer to is in the beginning of Mr. Horn's paper he mentioned that they were considering this question of transport accident followed by fire. Again, if that is so, you cannot assume that your cask will be in any particular orientation. You will notice that in Mr. Horn's test, when the crack was at the bottom, a very considerable quantity of lead has been lost in each case. In fact, Mr. Horn's results and his conclusions are full support of what we should expect. I think you will see that what my colleague, Mr. Frank Dixon will say, will be very consistent with what Mr. Horn has found.

Session Chairman: The United States Army has a few shipping problems of their own. They are concerned with shipping missiles, with sensitive electronics systems. They are concerned with shipping such things as tanks. These compare in size and weight to our own shipping containers. When we each learned of the other's interests and problems in shipping, it was very natural that a testing program of benefit to both agencies should result. This wedding of interest took place only a few months ago, and the plans are still in the embryonic stage of development.

Mr. Robert Meldrum, an engineer with the office of the Army's Chief of Transportation, is here to describe the concepts and plans made to date on a carrier vehicle container testing program.

A PROPOSED STUDY OF RAIL AND HIGHWAY TRANSPORT SYSTEMS DURING A CREDIBLE ACCIDENT

by
Robert Meldrum
Transportation Engineering Division
Office, Chief of Transportation

INTRODUCTION

It is a great pleasure for me to represent my office, the Office Chief of Transportation, Department of the Army, and I can assure you that we are delighted to have the opportunity to participate in this Symposium on Packaging and Regulation Standards for Shipping Radioactive Materials, being sponsored by the Atomic Energy Commission.

We in the Army have a mutual interest in this area. Your problems are our problems. The development of Regulation Standards and Procedures that will provide the maximum practicable safety at minimum cost in the shipment of radioactive materials involves many determinations.

The papers and discussions presented at this symposium give a feel for the magnitude of the determinations yet to be made. These papers and discussions have covered various types of tests that have been conducted and are being continued to advance our state of the art.

This paper is to discuss a different type of test, a test which only a few years ago could have been criticized as ridiculous and absurd. However, today's technology of testing and recording of experimental phenomena makes the test to be discussed practicable and feasible. The only question that remains - IS IT NECESSARY.

There can be no question on the necessity to establish standards of safety for protection of health and minimization of danger to life and property when dealing with and during transport of radioactive materials. The papers and discussions presented at this symposium are an approach to the difficult question of design of containers and transport systems in relation to the factors that have to be taken into account by competent authorities in approving Regulations, Procedures, Standards and the Specifications for Design of the Casks.

There are many aspects where more information is desirable and which, in fact, is mandatory if a better appraisal of this difficult field of activity is to be made. The proposed study discussed in this paper is one of these areas in which more information is essential.

To date, the Army shipment of radioactive materials other than weapons has not been of such quantity that would bring about an immediate concern. However, scheduled rates of increase over the next few years necessitates the establishment of sound regulations, standards, procedures and specifications for the design of shielding components and structures that will provide maximum standardization, greater economy and safety.

Because of this mutual interest, several joint meetings have been held during the past months with representatives of the AEC and the Office Chief of Transportation. These discussions have resulted in a coordinated pursuit to plan studies that will provide the technical information and basis for establishing the desired optimum standards.

This paper is to give a preview of one of the joint areas of study. This study is concerned with the magnitude, orientation and distribution of shock forces occurring during rail and highway accidents. Mr. Harry Clarke, of the Franklin Institute, and I have been selected to spear-head this study. Captain DeFatta, TC-AEC Liason Officer, has been performing as our secretary and coordinator. Our immediate concern is to develop the plan, program and cost of the study for review and final approval by AEC and TC headquarters. The objective and purpose of the study are as follows:

OBJECTIVE OF STUDY

To provide a realistic basis within the state of the art for establishing standards, designs and procedures that will assure maximum practical safety at minimum cost in the transport of radioactive materials.

PURPOSE OF STUDY

1. To determine the magnitude, orientation and distribution of shock forces in transport systems when subjected to rail and highway accidents.

2. To develop criteria for designing radioactive material transport systems that will withstand credible rail and highway accidents.

3. To develop technical information that will facilitate the movement of radioactive materials and provide guidance to overcome unnecessary restrictions imposed by Federal, State, Local and Private authorities.

4. To develop criteria for establishing regulations, standards and procedures that will bring about an optimum balance between safety and economy in the transport of radioactive materials.

DISCUSSION

This paper is to provide information on the status and tentative plan for pursuit of the study.

In our planning we considered it essential to establish certain ground rules. These ground rules would insure the validity of the results and reduce to a minimum any criticism as to the authenticity or realism of the conditions of the study.

I am sure that those of you here who have been responsible for experimental work have been faced with the question that the experimental conditions were not representative of the actual conditions. In this proposed study we plan to avoid such after remarks.

The adopted ground rules for the proposed study are as follows:

1. The shielding structures to be used in the study would be representative of items presently in use.

2. The shielding structures would be representative of types most likely to be standardized.

3. Rail and highway vehicles would be representative of types used during actual transport.

4. Tie-down and restraint procedures would be representative of methods employed during actual transport.

5. Conditions of the study would be based on accident statistics and probability rates of the various types of accidents.

The study will consist of creating rail and highway accidents with shielding structures, rail and highway vehicles and conditions meeting the ground rule requirements.

A survey was made to determine types of radioactive containers to be used in the study. This survey revealed that there are more than 13,000 such containers in use. There can be no question that standardization in this area would bring about greater economy. A final selection as to types of containers has not been made. However, for the highway study, it has been decided to obtain containers representative of the following weight categories:

(1) 1000 lbs. to 2 Tons

(2) 5 Tons to 6 Tons

(3) 12 Tons to 15 Tons

For the rail study, containers will be selected from the 20-Ton to 120-Ton weight categories.

It is intended that containers selected for this study will provide correlation of results of previous tests such as those discussed during this symposium.

Having made a proper selection of containers, it is then equally important to select rail and highway vehicles that are representative of types of equipment used during actual transport.

A survey of this area has indicated that shipments are usually made on standard commercial vehicles of a type normally selected by the carrier. Some carriers have modified their vehicles to make them more adaptable for the specific loading conditions. Our preliminary investigation indicates that there is a need to develop approved regulations, standards and procedures in this area.

Our survey is sufficiently complete so that a final determination can be made on the types of vehicles to be used in the study. The types of vehicles that will be used are as follows:

Highway Vehicles:

Load Weight	Type Vehicle
1000 lbs. to 2 Tons	Van Trailer
2 Tons to 6 Tons	Stake Side Trailer, High Bed
12 Tons to 15 Tons	High Bed Trailer

Rail Vehicles

Load Weight	Type Vehicle
20 Tons to 60 Tons	Gondola Car
60 Tons to 120 Tons	Special or Depressed Rail Car

It will be noted that all highway vehicles are of the nigh-bed type. However, it has been considered desirable to include in the study a low-bed type trailer to determine the effects of the lower CG, particularly with the higher concentrated loads.

It will be of interest to mention here, that informal consultations have been held with Mr. Keller, Vice President, Research Center, Association of American Railroads, and Mr. Hulse, Vice President, Truck Trailers Manufacturers Association.

Each of these gentlemen has expressed great interest in the proposed study, and have indicated that they would assist in any way requested. It is considered that they can provide expert consultation in their respective fields, and it is planned that they will serve as part of a consultant group when the proposed study is officially approved. In addition, representatives of the following agencies will be contacted in the near future and will be invited to serve as consultants:

American Trucking Association
Highway Research Board

Bureau of Public Roads
Bureau of Standards
Fire Underwriters
Interstate Commerce Commission
National Safety Council

As the proposed study develops there no doubt will be others.

Thus far, we have discussed types of shielding structures and vehicles. It now remains to discuss the conditions of the study or types of accidents to be reproduced.

The subject of this paper makes use of the words - Credible Accident. Available statistics to evaluate the accident conditions thought "Credible" leaves much to be desired. When considering the National interest to reduce accidents, it would appear that those engaged in this field should be encouraged to provide more detailed statistics on the conditions of the accident.

The Johns Hopkins Report NYO-9773, prepared by Professor Thompson, was used in determining accident conditions to be reproduced in this proposed study. Figure 1 indicates the probability density for the respective accident conditions and their impact velocity. The Interstate Commerce Commission is currently providing additional information which will be used in making a final determination of the accident conditions.

The conditions of accidents being considered for this study and which have the higher probability rates and damaging effects are as follows:

Head-On Collision
Rear-End Collision
Side Impact
Overturn

Figure 2 illustrates the head-on collision. A special bumper provided with dynamometers to measure the actual impact force will be attached to the truck tractor frame. The truck tractor frame, semi-trailer structure, tie-downs, and the shielding structure will be provided with transducers located in a manner that will give the load-time or shock force time phase through the system.

Of special interest at this point, the Truck Trailer Manufacturers Association is currently working with the Interstate Commerce Commission in establishing load concentration standards for interstate operation of highway trailers. All vehicles used in this study will be loaded in conformance with these standards.

Bumper heights will be kept uniform. A structural analysis will be made on the selected semi-trailer to determine spring rates and structural stiffness constants so that the result can be correlated with other structures with known characteristics.

A collision velocity similar to that shown in Figure 1 for head-on collisions and having the higher probability density, 40-45 mph., will be made. The vehicles will be operated by a remote control system.

Figure 3 is a schematic illustration of the rear-end collision. The test vehicle in this case will have zero velocity. The colliding vehicle will be operated at an impact velocity of from 20 to 30 mph. Also, the colliding vehicle will be provided with a dynamometer bumper to measure the actual impact force. The test vehicle will be equipped with transducers to determine the shock force time phase relationship of the impact.

There is no question that the distribution of the shock forces in this condition will be different from that for the head-on collision. It would appear that the test vehicle running gear and center plate connection are the principal reaction members. How these members distribute the force through the semi-trailer is problematical. However, when the physical characteristics of the semi-trailer are known, a theoretical analysis will be made to establish, if possible, correlation with the test results.

The next condition of interest is the side collision, Figure 4. The test vehicle will be located so that the colliding vehicle will impact the test vehicle's semi-trailer midway between the center place and rear running gear.

Since the semi-trailers used in these studies are of the high-bed type, it will be obvious that for this particular case the initial points of contact are questionable. The bumper of the colliding vehicle will be at a height less than that of the test vehicle semi-trailer bed or floor.

No doubt the engine hood of the colliding vehicle will contact the semi-trailer floor. But it is of low structural strength and will soon buckle. Simultaneously, it can be expected that the colliding vehicle bumper will contact the semi-trailer main structural members. But again, these members have low structural strength in this plane and will buckle. However, in so making this contact, it could bring about an overturn of the semi-trailer. This, to some extent, will be dependent on road friction and the structural strength of the semi-trailer king-pin connection. The shock forces on the shielding container during this case will be of considerable interest.

Next, we come to the overturn condition. This is illustrated in Figure 5. It may be mentioned here that a final selection of a site for these studies has not yet been made. They will, however, be conducted on Government property. This will permit a more flexible operation and certainly will provide for better control.

In any event, for this particular case, the test vehicle will be representative of a vehicle going over an embankment. It has been decided that the overturn be made at a predetermined location. This can easily be accomplished by constructing a super-elevated ramp.

Boulders, rocks, etc., can be placed at the location of overturn. Two or three embankments will be constructed to bring about several overturns of the vehicle.

After the overturn and collection of the data, a fire will be created. Without prior knowledge, a local fire company, several miles away, will be contacted to extinguish the fire. All details, such as working experience, knowledge, handling procedures, time lapse, etc., of the local fire company, will be recorded. It is expected that this exercise will be of much interest and certainly will bring out some weakness in procedures. Also, it will be useful in evaluating the thermal integrity of the shielding container.

This covers the four conditions presently established for the highway portion of the study. A structural analysis will be made on all vehicles used in the study so that a correlation can be made with the obtained. The analysis and the results will provide the technical information to evaluate the relative performance of highway vehicles and shielding containers during the most likely credible accidents. Also, it will provide the criteria for designing radioactive material transport systems to withstand these accidents.

Particular attention will be given to the selection of the instruments and their location. All data will be automatically recorded on magnetic tape. This data will be supplemented with high speed movies so that an accurate and positive recording of the phenomena can be made.

The foregoing covers the highway study. I would like, now, to briefly discuss the rail study.

Again, cumulative statistics on rail shipments of radioactive materials and rail accidents leaves much to be desired. It can generally be concluded that high density loads, 90-Ton and over, are shipped in special rail cars. Loads between 10 and 80 tons are shipped in box-cars gondola and depressed center type cars.

Our survey of rail accident statistics has not been finalized. However, as of the moment, the two conditions that appear to have the higher probability density are rear-end collisions and derailments involving overturns. When the survey has been completed, additional test conditions may be necessary. Present planning is considering at least these conditions.

As in the highway study, a final selection as to types of shielding containers has not been made. In any event, containers of the medium density type which can be shipped either by rail or highway will be selected for one phase of the rail study. This will provide correlation of data between rail and highway accidents.

Types of rail vehicles to be used will consist of box cars, gondola and depressed platform cars. The test vehicle will be assembled in a train consist representative of actual freight movements.

For the rear-end collision study, the test vehicle will be located at the rear end of a train make-up. A colliding train consisting of 30 to 40 rail cars will be impacted into a test vehicle at about 40 mph. Shock forces occurring during this condition are estimated to be 3.5 - 5 million pounds. During one phase of this condition, special tie-down arrangements will be provided to restrain the shielding container to the vehicle. These tie-downs will be equipped with special instruments to measure forces transmitted to the container, at least until such time as complete buckling of the vehicle occurs.

The derailment study will consist of a complete train make-up of from 30 to 40 rail cars. The test vehicle will be the 4th or 5th car from the rear end of the train. The test track will be arranged to cause a positive derailment. The train will be operated over the test track and when the third car ahead of the test vehicle passes the derailment point, the track will be energized to cause the derailment. The test car and cars immediately ahead of and behind the test car will be derailed and rolled over the embankment.

The foregoing is a fast review of our present plans for the conduct of the study. Some modifications and additions will unquestionably be made during the preparation of the final plan. It will be obvious that to prepare a plan and program for this unusual study requires as best as humanly possible, a thorough and comprehensive understanding of all conditions of the study. It is a one-shot target and no mistakes or overlooks can be tolerated.

INSTRUMENTATION

This brings us to the next point of interest - Instrumentation. If the phenomena cannot be accurately recorded, there would be no purpose of conducting the study.

Instrumentation and testing technology has advanced to a degree whereby an accurate recording of the phenomena can be made. Because of the magnitude of the forces likely to be encountered some special instruments will have to be designed. However, this will not create any unusual difficulty. Conventional transducers, accelerometers, strain gages, dynamometers, potentiometers, etc., will be used as far as practicable. Colliding vehicles will be operated by a remote control system. All phenomena will be telemetered to a tape recording system housed in separate vehicles near the site of the collision conditions.

Since the orientation of the forces that will be transmitted to the shielding container are not predictable, special consideration must be given to this area. It might be possible to arrange a self-contained recording system, with transducers located circumferentially to measure normal and vertical forces as well as those occurring in the longitudinal and transverse planes.

It will be seen that the same thoroughness must be exercised in the selection and design of the instrument and recording systems. These

systems must record all phenomena and the time phase relationship of occurrences to accurately evaluate the shock force history. As was indicated previously, instruments will be located so that correlation with the theoretical and physical results can be made.

RAIL AND HIGHWAY VEHICLES

The types of rail and highway vehicles to be used have been discussed previously under the conditions of the study. Dependent upon the final selection of the types of shielding containers to be used, it is tentatively estimated that 35 rail and highway vehicles will be used and probably destroyed in the study.

This may be considered an extremely high price to pay for technical information. However, this cost will not be as high as it may first appear. The vehicles will be used and their original cost will have already been amortized. Their physical characteristics and structural integrity will be equal to that of vehicles presently used by the carriers.

About 40 per cent of the vehicles are already laid aside and earmarked for the study. The Truck Trailer Manufacturers Association has assured that there would be no problem in obtaining the required vehicles at a nominal cost. Government equipment will be used as far as practicable.

CONCLUSION

In the foregoing, I have attempted, in a short time, to discuss a proposed study, a study which can provide a realistic basis within the state of the art for establishing standards, design and procedures that will assure maximum practical safety at minimum cost in the transport of radioactive materials. This study can create, if not international, certainly national interest.

The shippers, you in the Atomic Energy Commission, we in the Army, are more familiar with our technological advancements. We must equally provide technological advancements in transportation and pass this technology, know-how, and guidance on to the common carrier so as to insure the most effective and efficient transportation of our sophisticated items.

It is believed that the coordinated approach can best bring forth results commensurate with the demands and challenges that are being placed, and will continue to be placed, on our transportation systems.

Again, may I express my pleasure for the privilege of participating in your symposium.

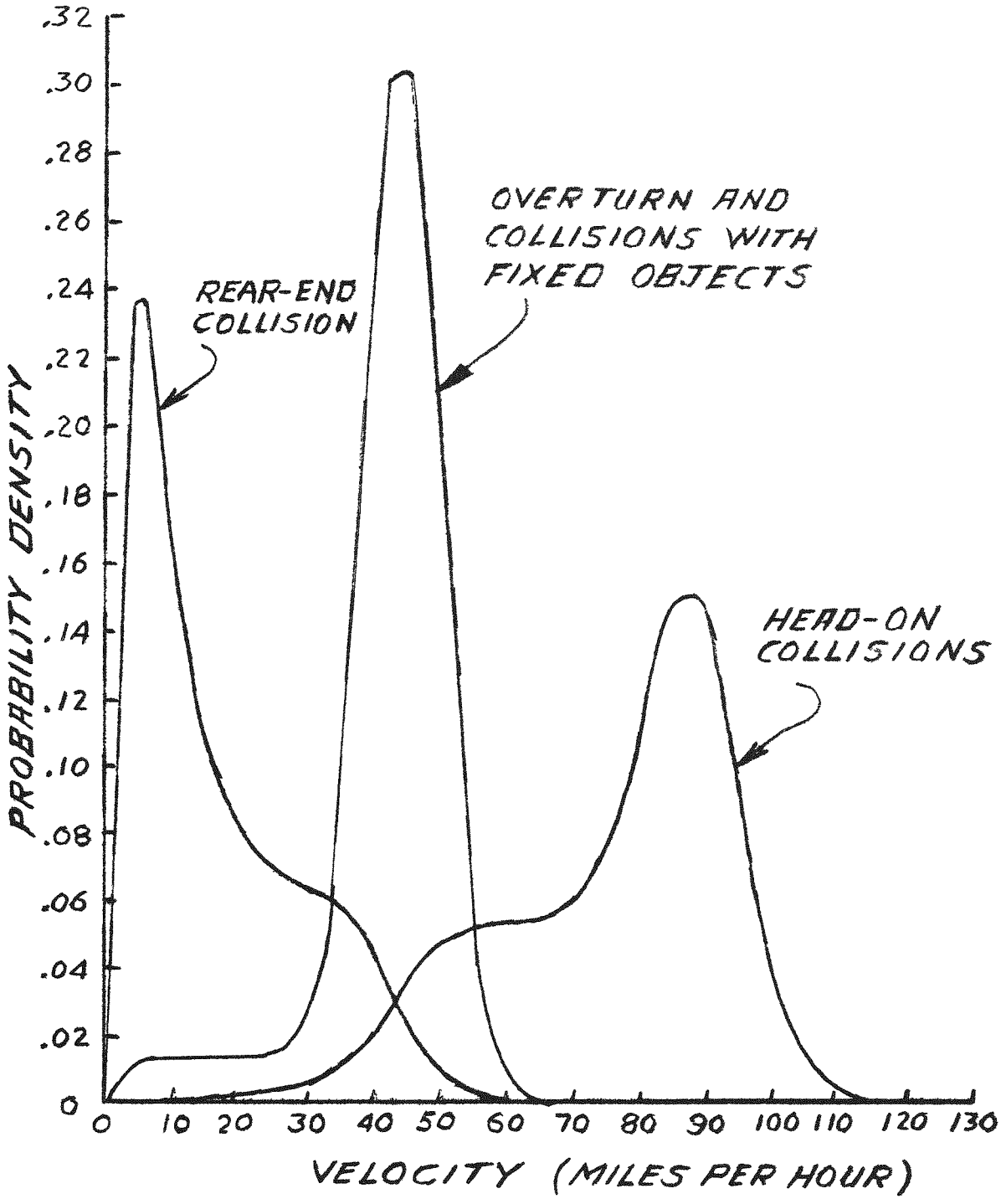


FIGURE 1. DISTRIBUTION OF NET IMPACT VELOCITY IN VARIOUS TRACTOR-SEMITRAILER COLLISIONS

JOHN HOPKINS REPORT NYO-9773

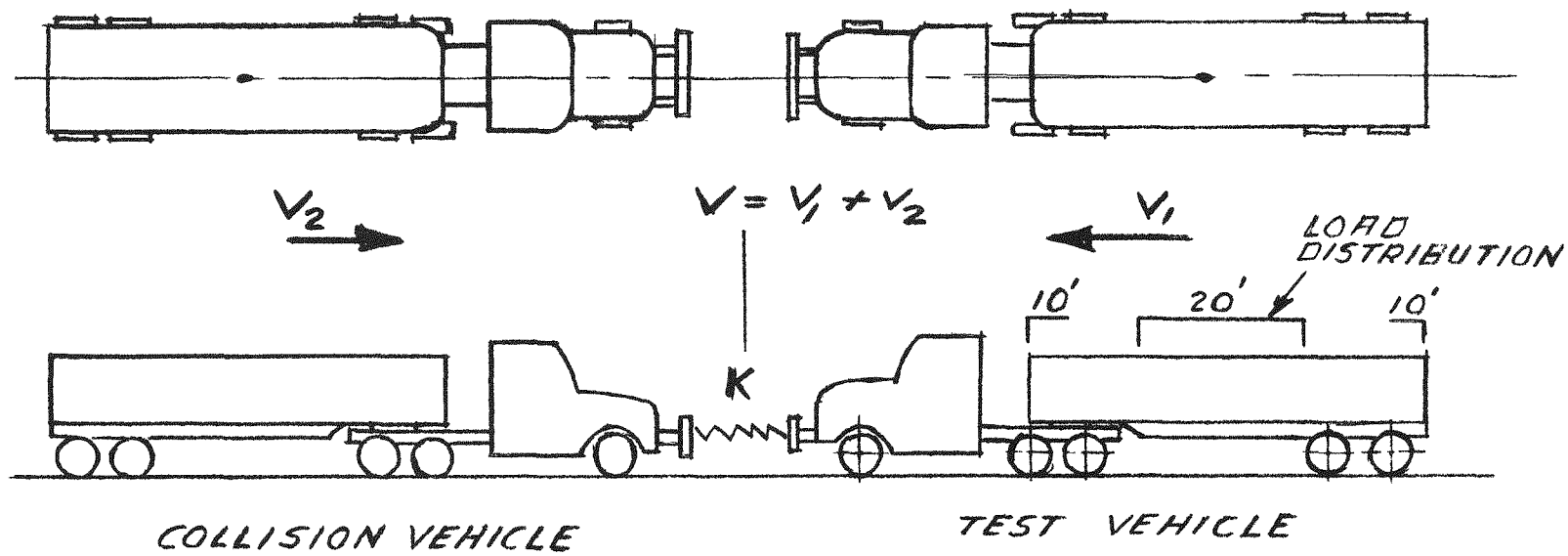


FIGURE 2.
HEAD-ON COLLISION

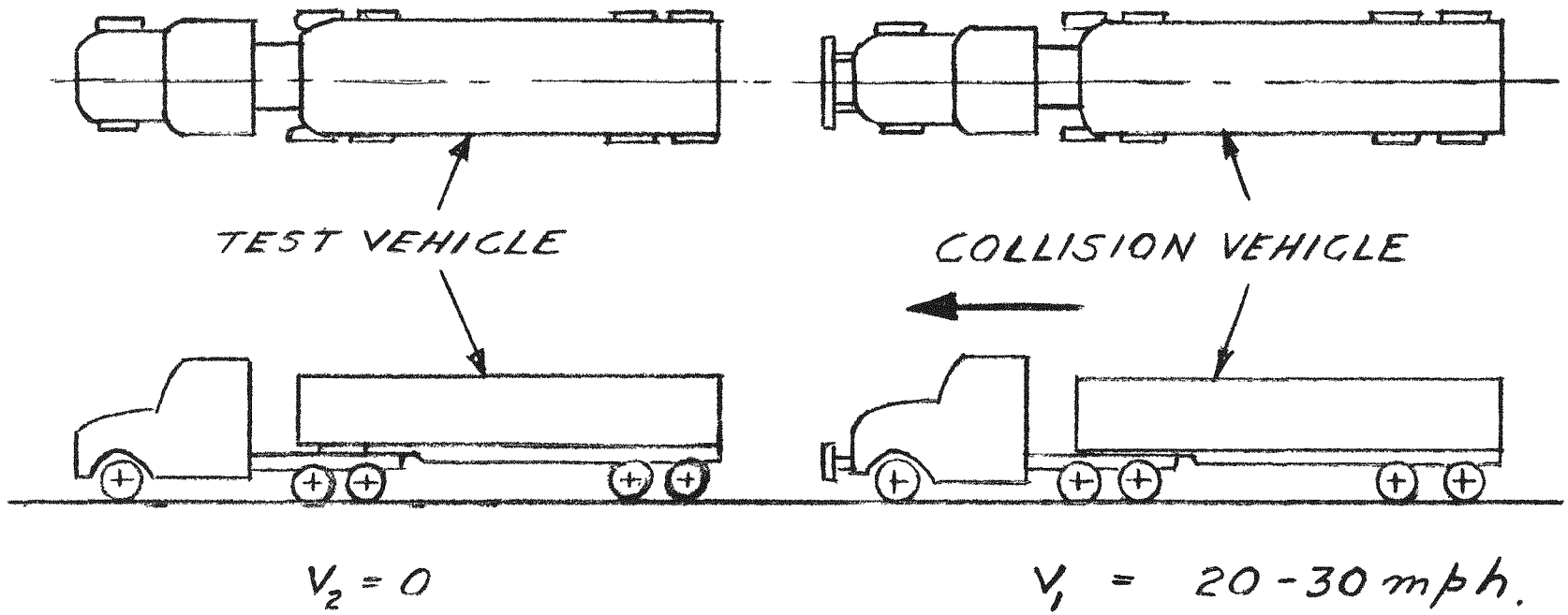


FIGURE 3

REAR-END COLLISION

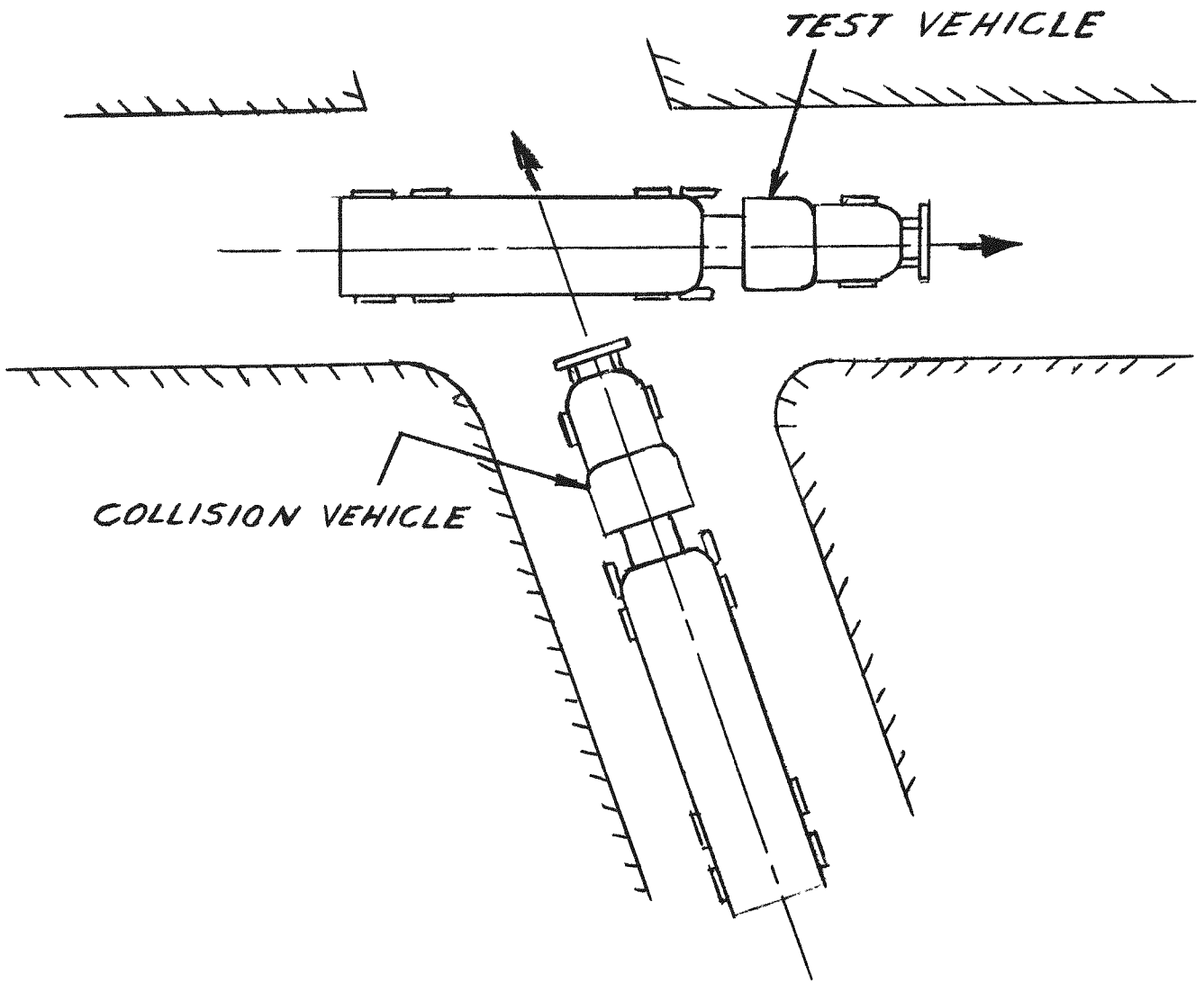


FIGURE 4. SIDE COLLISION

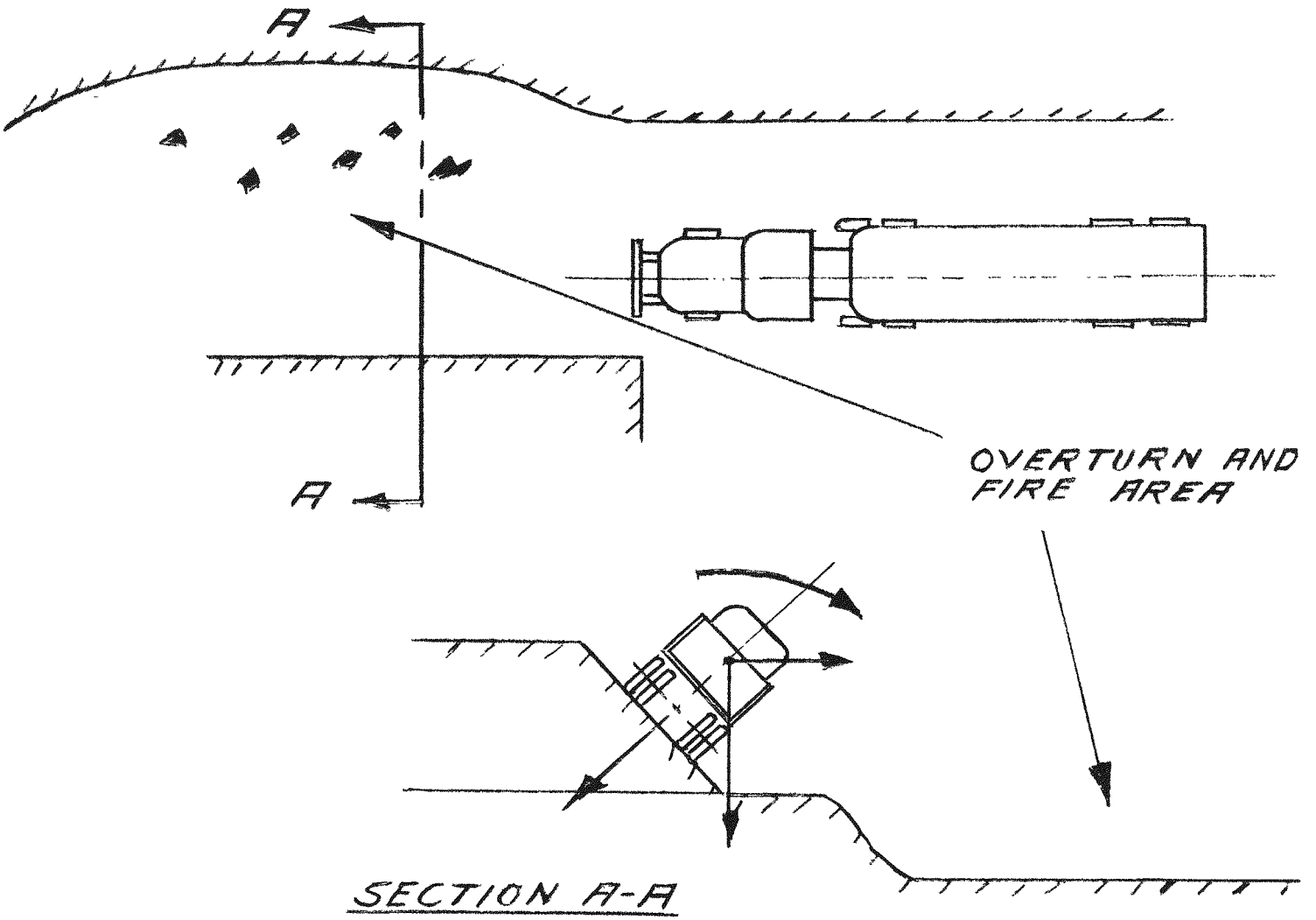


FIGURE 5. OVERTURN AND FIRE TEST

Remarks by Mr. Meldrum: It is known to all of us that the geometries of vehicles vary all over the lot. Our bumper heights are uneven. Our point of contact is not always anorm. However, in the vehicles we have selected for the study, we will select a common height. Behind each bumper we will provide an instrument to measure the true impact force of the two vehicles. Complete studies will be made of the vehicles to determine their spring rates and stiffness factors so that we can relate this data to other vehicles.

Mr. Hulse of the Truck Trailer Manufacturers Association indicated he was coordinating a study with the ICC to provide a standard that will determine the loading on a flatbed vehicle. We are dealing with highly concentrated loads, and it is natural when we put a highly concentrated load in the center we have extreme deflection of the vehicle, and the vehicle has a tendency to bend. In the study they are able to determine guidelines as to the amounts of concentration. As I recall over the spread of about 20 feet the figure is about 25,000 pounds, which is half the weight of some of our containers. On the following 10 feet of each side I think the figures are about 15,000 pounds, which makes a total weight of about 50,000 pounds.

In our study, we plan and hope to be the first to put into effect these standards. All of our loadings shall comply with this standard. We will watch our load concentrations. If we have a high density load, we will be sure that it is distributed in accordance with the standards.

For rear-end collision, the test vehicle will have zero velocity. As I indicated previously, the rear-end vehicle which will collide with it, will be traveling at about 20 to 30 miles per hour. I believe it is obvious that in this test, again looking at the point of contact, that the bumper will come under the platform of the test vehicle. Our reaction points are at the center plates and the running gear. How this force will be distributed into this vehicle is somewhat questionable. However, again we will have this instrumented in order to determine these forces, the actual size of them and how they are located.

On tie-down, we must treat the entire truck or train as a mass. The second philosophy of tie-down is to build in enough strength that it will retain the cask until the complete energy of the impact has been spent, and at this time the cask will be released and will go on its own way as a free body.

We are extremely interested in the last phase, a design of tie-down systems that will provide maximum impact and buckling of the vehicle to absorb the energy of the impact, rather than put this into the cask.

DISCUSSION AND COMMENTS

It was noted that Westinghouse is shipping large reactors for the Navy and has built and are using today casks that are in excess of 280,000 pounds. It was suggested that the rail shipment study be extended to 150 tons because of casks that are being designed in excess of 300,000 pounds.

Johns Hopkins University dealt only with highway accidents and the analysis of these accidents in an attempt to bring forth some balance between the elements that go into the cost of a shipment, including the expected hazard cost. Little or nothing was developed about railroad wrecks.

Agreement with this proposal was expressed since one of the essential things that we must have are the capacities of vehicles to absorb energy. Any engineer

if the costs were known, could design a vehicle with a buffering device that would be perfectly possible of shielding the casks with a force of zero in the most incredible accident.

The greatest difficulty in all this work is predicting the speeds and attitudes at which vehicles collide in the random circumstances of accidents on the highways. It should be possible to determine that speed.

When an accident occurs, and no one has measured the speeds, all one has are prejudiced opinions and mostly falsehoods about what happened. Any one who ever had an accident or who is responsible for it believes he was not going quite as fast as others. It is possible to put on every commercial motor vehicle which transports any dangerous goods and instrument known as a recording tachometer to report every instant of that vehicle's movement, and the velocity at which the vehicle is moving. In case of accident, the record would be complete to the instant of contact.

It also provides means of control of the driver. There are many of them in use and they are not too expensive. I would strongly recommend that wherever dangerous goods are carried, a tachometer be used.

Session Chairman: The United Kingdom has given transport problems much study. This is obvious not only from the sophisticated papers on the subject that we find in the technical listerature, but also from the considered and constructive comments made by the very able representatives at this meeting.

Now, we will hear from Mr. Frank Dixon, Research Group, Atomic Energy Authority, United Kingdom of Great Britain and Northern Ireland.

T.C.A.P./P.64

UNITED KINGDOM ATOMIC ENERGY AUTHORITY

RESEARCH GROUP

The Design of Shielded Containers to I.A.E.A. Standards

by

F. E. DIXON

INTRODUCTION

1. This paper is concerned with the problems encountered in the design of load shielded containers to I.A.E.A. standards, since these alone present a research problem and represent the bulk of containers in use in the transport of radioactive materials. Fissile material containers are amply covered by the work of Mr. A. Grange of A.W.R.E. and are not included here, except for exempt quantities.

2. In this paper the design of shielded containers is discussed rather than the design of packages, because the designer usually designs a shielded container and not a package since in many cases all the range of purposes of the container is not known at the time of design.

3. Shielding thickness is a matter that limits the design to a container since the customer will usually specify a cavity size to carry x curies of isotype y and then later use it for something quite different in energy and form. The packaging takes care of the physical form, the shielded container of the emergent radiation and the assembly of these two of the safety of the unit.

The solutions to the design problems tend towards a form of package but are not in themselves complete packages, since by definition a package includes everything from the active contents to the outermost surface.

4. Cast iron, steel and heavy metal are not included in this paper since on a weight basis C.I. is inefficient, a C.I. pot weighing 55 lbs being equivalent to a 42 lb lead pot, and heavy metal and depleted Uranium very expensive, difficult to work and limited in size. These pots would also need insulating to prevent the contents being affected by heat and causing a pressure build up in the fire test. Cast iron is also suspect due to the effects of thermal shock.

5. The tests devised by A. H. & S. B. in their report, "The transport of radioactive materials, interim recommendations for the application of environmental tests to the approval of packaging[1]", have resulted in the need for a new technique in some aspects of container design. In particular there are two tests, (a) the fire test at 800°C for 30 mins., (b) the drop test of 30′ on to a steel faced concrete beam, which have a significant effect on existing design principles.

6. Until the issue of the I.A.E.A. regulations, sound engineering principles had resulted in containers which stood up very well to the hazards of transport but, however, these had never been subjected to anything approaching the maximum credible accident proposed in the tests. The drop test on its own presents no great difficulty since tests have shown that modern containers may be dropped from 30′ without damage sufficiently severe to cause a release of the contents, this is illustrated in A.W.R.E. memorandum W.D. 3/101/61.

7. Reactor fuel flasks are a special category and are not necessarily as strong due to their length to width ratio but if advantage is taken of the relaxations proposed for heavy containers carried as an integral part of the vehicle transporting them, then there is no reason to suppose that they will prove inadequate.

8. A drop test usually results in the fracture of a weld in the containing shell and it is this fracture which presents the problem in the subsequent fire test, (it is a feature of the A. H. & S. B. proposals that effects of tests are additive.)

9. Lead is an extremely fluid metal when liquid and melts at between 315°C and 320°C[2] so that the existence of any free passage through the containing shell would result in failure of the container in a fire. A typical example of this was observed while a 6 cwt. container was undergoing a fire test at A.W.R.E. During this test lead was noticed running freely from one side of the container, this proved to be due to the breakthrough of a drill point in the steel shell. (There is no record of this test), and as a result a considerable amount of lead was lost in a short time.

10. The paper is divided into two main parts, the first of which discusses the effect of heat on lead filled containers and the second discusses methods of protecting lead and lead filled containers from heat and mechanical damage.

EFFECTS OF HEAT ON LEAD FILLED CONTAINERS

11. The lead used in lead filled containers is usually a 4% antimonial lead, used because of superior strength properties and lower viscosity than pure lead. It melts at 315–320°C depending on the number of times it has been melted but small pockets of the eutetic alloy melt at about 250°C, the whole mass being pasty at 295°C[2]. The viscosity of liquid lead at 800°C is 1·18 centipoises[3] compared with 1·002 for water at 20°C[3], it has a low total heat 28·2 B.Th.U per lb[4] and expands 6·1% from solid lead at 20°C to liquid lead at 327°C and further up to 12·28% at 800°C. The increase of volume on change of state to liquid at 327°C is 4·1%[4]. It can easily be shown that if a mild steel container is full of lead at ambient temperature that it will yield at about 250°C due to differential expansion and if the welds do not fracture it will go on expanding and cause (at a temperature as low as 350°C) a permanent set in the container which will be of considerable importance from the shielding point of view (Expt. 5, Fig. 1).

12. For preliminary experiments two existing containers were used, the first one being a Krypton 85 container formed of two concentric Mild Steel tubes of 1″ and $1\frac{1}{2}$″ nominal bore closed at the ends with screwed plugs and the annular space filled with lead. This was heated in a laboratory furnace to 800°C which took 90 mins., and afterwards sectioned; the lead had forced its way past the screw threads at the end of the tube and nearly half filled the centre cavity, shielding effectiveness was reduced to zero on the one side.

The lead lost was greater than the 12% volume change and the excess was most likely due to the expansion of the air trapped while filling the space with lead. (Expt. 2, Figs. 2 & 3).

13. The second experiment was a steel cased lead pot 6″ dia. × 7″ high with $\frac{1}{8}$″ thick casing, in this case the steel shell was mainly to provide attachments for support and closure. The pot was heated to

370°C, the base weld fractured and as shown on the X-ray, Fig. 4, about $\frac{3}{4}$ of the total volume of lead was lost. Examination of the weld showed that a good part of the weld had been ground away on "cleaning up" only about $\frac{1}{16}$" of the weld thickness remaining.

14. It was now obvious that to obtain reliable results special containers would have to be made for test and two steel clad lead filled containers were made, one with the welds radiographed and one with unradiographed welds, in each case the lead was machined to fit the cavity in order to avoid errors due to lead shrinkage. (Figs. 5 & 6).

15. The radiographed container was heated to 348°C and on cooling it was observed that due to the fracture of a weld, a quantity of lead amounting to 2·1% of the original volume had been lost. As a result of permanent set, the steel shell had increased in length by ·022 inches and in diameter by ·030 inches in addition the base plate was bowed to the extent of ·092 inches at its centre. If the increase in volume due to permanent set is added to the volume of the lead lost and due account taken of linear expansion due to temperature rise, then the total increased volume of lead would amount to 6% as would be expected. Calculations show that the pressure needed to deflect the bottom plate ·092" was between 1,200 and 3,000 lbs. per sq. in., either figure will give a stress in the side walls above the yield point of M.S. at 348°C. Because of this failure it was not considered necessary at this stage to test the second container.

16. To improve the performance in a fire, a toroidal void was introduced into a container before lead filling, this void being in the form of an evacuated brass ring. The ring was evacuated so that there would be no entrapped air which could give a pressure build up of approximately 60 p.s.i. due to expansion. The filling holes in this container were closed by bolts scaled with copper washers. The container was heated to 358°C but the pressure of the lead extruded the metal past the threads and sealing washers and left a void at the top of the container, because of this the intentional void did not collapse. (See figs. 7 & 8).

17. Another container with a similar void but of all welded construction was then tested at 800°C for 50 mins. In this case the void collapsed and the brass ring alloyed in the lead. Due to the further expansion after melting, the container sustained permanent set but did not leak. A large void was discovered on sectioning the container after cooling, again showing that due to the indeterminate position of the void there was little future in this method of protection. The lid of the container was not fitted with a void, a weld cracked at the bottom and assisted by entrapped air approximately 75% of the lead was lost. (See Fig. 9).

18. The disposition of the void is interesting since it provides one of the most pertinent points against using voids, i.e. that the position of the void after an accident cannot be predicted, it is also easily shown that to provide a void of 12·5% of the volume or to attempt to provide extra shielding to compensate for the void would be uneconomic. (See Figs. 10 & 11).

19. To determine the temperature at which a container cracked, an experiment using the non radiographed weld container was set up. It was placed in an electric furnace at 350°C and when the thermocouples on the container recorded 290°C lead was seen dripping into the tray on which the container was set. When the door had been previously opened at 280°C there had been no leak of lead. The lead in the container need not necessarily have been molten when the container split since any lead extruded through the crack would melt in the furnace atmosphere.

CONCLUSIONS ON THIS SERIES OF TESTS

20.
1. It is not practicable to design a steel clad lead filled container that will not leak lead in a fire test.
2. The damage occurs at about 280°C.
3. Voids are not a practical solution since their inclusion is difficult and the position of the resultant post fire void is indeterminate, the orientation of the container having a great effect on the increase of the dose rate.
4. Voids cannot be relied on since the lead does not always melt where the void is included.
5. The addition of extra shielding to cover the loss due to the void is uneconomic.
6. Included air is a danger and will cause a greater loss of lead in case of leak.

PREVENTION OF THERMAL EFFECTS ON CONTAINERS

21. At this point it was decided that mechanical and thermal protection were necessary to give an efficient container and a train of experiments to find an economic solution were set in hand.

22. Wood was chosen since it was a good insulator[5], it is mechanically strong, (Iroko gave a u.t.s. of 4·1 tons sq. in. along the grain and ·85 tons sq. in. across the grain[6] is not severely affected by fire in bulk and is reasonably cheap and easy to work.

23. The first experiment in this series was a U pot (a bare lead pot $3\frac{1}{4}$ dia. by 5″ high, weighing 13 lbs.), this was placed inside a teak liner $1\frac{1}{2}$ thick inside a 16 G mild steel drum. This assembly was put into a furnace at 800°C for 30 mins, and the maximum recorded temperature at the surface of the lead pot was 96°C. On sectioning after cooling, charring to a depth of 1″ maximum was observed. (See Figs. 12, 13 & 14).

24. Tests were then carried out to determine if a more economical timber was suitable and a comparative furnace test on Teak, Iroko and Elm using a U pot $3\frac{1}{4}$″ dia. × 5″ high with $1\frac{1}{2}$″ of wood shielding inside a 16G mild steel drum was carried out. The temperatures are recorded on Graph 1 showing that Iroko is an acceptable alternative besides being about $\frac{1}{3}$ the price of teak. Elm was not satisfactory, the temperature just reaching the melting point of lead at the end of 30 minutes. Iroko is readily available and easy to work.

25. A teak container was made to house the unradiographed weld container. This was dropped at Aldermaston (A.W.R.E. Memorandum WD3/106/61) no damage being sustained by the container or cladding. It was then fire tested at 800°C for one hour, the maximum charring being $\frac{3}{4}$ to 1″ and the temperature at the interface 80°C. (This cladding was of a laminated construction and 3″ thick, see figs. 15, 16, 17, 18 & 19).

CONCLUSIONS ON THIS SERIES

26. (1) Hardwoods are a good thermal barrier.
(2) Hardwoods are mechanically strong.
(3) There is no significant scale effect.

DESIGN OF A PROTOTYPE CONTAINER

27. Following the success of the experiments on thermal insulation it was decided to design a container which could be the basis of a family of containers for use in the isotope traffic, this family to cover the whole range of type 'B' shipments excepting those which require special purpose containers. A container with a cavity of 2·2″ dia × 3·9″ deep and a shielding thickness of 1·9″ capable of being increased to 2·4″ by the insertion of a lead liner into the cavity which would then take a standard isotope can, was proposed by I.P.U. as being a suitable size for a protoptye. The container was made in bare lead with a steel lifting strap which also provided the anchorage for the lid closing and sealing device. The finished pot weighed 88 lbs. A wooden liner 2″ thick, with a cavity to take the pot plus a layer of engineers hard white felt to provide a snug fit, was made in Beech. These were cased in a standard steel drum for the convenience of attaching customs documents and also for an extra degree of water tightness. The drum was drilled in eight positions and mild steel patches soft soldered over the holes to provide pressure relief in case of fire. The assembly weighed 118 lbs. To enable greater loads to be carried another larger drum in which the previous assembly could be placed and centralised by a plywood spider was produced, this giving a total of 6″ of space shielding. The all up weight of the assembly was 150 lbs.

28. This weight which is 1·76 times the pot weight may seem excessive but a pot to carry the same curie content (assuming 200 mr at the surface of the outer drum) would weigh about 250 lbs and then would not pass the prescribed tests. This design gives three different assemblies, (1) the bare pot as a type A container, (2) the small drum, liner and pot as a Type B1 container, and (3) the large drum, small drum, liner and pot as a Type B1 container with space shielding, see Figs. 20, 21 and 22.

29. Drop and fire tests were carried out. The drop test memorandum from A.W.R.E. is not yet available, however, the fire test results are shown in Figs. 23, 24 and 25. As a result of both tests no damage was

sustained by the lead pot, the two drums remained sealed after the drop test and in the fire test the maximum temperature reached at the interface was 86°C. This temperature subsequently reached a maximum of 110°C after removal from the furnace. The tests proved the sound basis of the construction.

30. This is an extremely economical form of container since on a 25 off basis the cost would be about £30 all in, (the prototype cost £45) which compares very favourably with about £80 for a steel clad lead pot of similar capacity, but without the versatility of the new design.

FURTHER EXPERIMENTS ON THE USE OF WOOD AS A THERMAL INSULATION

31. The cylindrical wood liner and steel drum principle is obviously limited to the smaller type of lead and lead filled container up to about 15 inches in diameter. For the larger type of container a possible solution would be a thermal jacket in the form of a timber packing case.

(a) To provide a basis for the design of cases for larger containers a bare lead pot was placed inside a 3″ thick Iroko liner similar to that used in test 11 but this time no steel drum was used. The result was most gratifying in that no extra charring above that experienced in the clad test occurred, and the temperature rise at the lead pot was only 4°C. This is thought to be due to the fact that there is a very small pressure rise in the clad container which keeps the hot gases in, whereas in the unclad container there is no pressure build up so that all the hot gases can escape outwards. This was borne out by the fact that there were no condensed combustion products on this lead pot as appeared in previous tests, see figs. 26, 27 and 28.

(b) A similar test was carried out using a 2″ thick Iroko liner, and although the internal temperature was higher, 8°C, this was again lower than when using a clad timber shield. The felt insert was again unaffected by the combustion products.

CONCLUSIONS

32. 1. Wood insulated containers provide a cheap and simple solution to the design of type B containers.
2. Lead pots in these containers may be unclad as far as normal construction and handling methods permit.
3. That wooden packing cases may be used to shroud large containers, particularly where the drop test is not severe and will provide ample thermal insulation. (A test is in hand on a 15 cwt lead filled steel clad container contained in a wooden packing case, results of this will be available for the symposium.)

OTHER THERMAL INSULANTS

33. Consideration was given to other methods of packing using thermal insulants. The properties desired being resistance to shock and good thermal properties at 800°C.

34. Vermiculite was chosen as the insulator and a "soft pack" designed using a resin bonded wood wool liner to house the lead pot, these two being contained in a small steel drum. This assembly was then placed in an outer drum with a plywood spider and the interspace filled with vermiculite (Mandoval Grade 1). The small drum with the wood wool liner was dropped twice from 28′ on to the lid, (the highest point available for the test) with no significant damage to the contents, nor did the lid closure fail. On fire test the temperature at the interface of the wood wool and lead pot rose to 101°C. Very minor discolouration was present on the outer face of the wood wool, see figs. 29, 30 and 31.

35. This pack is some £8 cheaper than the solid wood type but is somewhat messy in use, this disadvantage could be overcome to some extent by enclosing the vermiculite in bags. Another disadvantage of this type of design is that it necessitates the use of two drums to fulfil all the requirements of a Type B1 container. However, it should be noted that the smaller drum with its soft pack is a first class Type A container for use with the medium weight lead pots.

36. Foamed phenodic resin of 4 lbs/cubic foot density was suggested as a good lightweight insulator but tests proved this to be unsatisfactory, the lead pot used in this case melting after 20 minutes, see fig. 36.

CONCLUSIONS

37. 1. "Soft packs" may be designed that are quite as effective as the timber insulated type for medium sizes pots possibly up to 200 lbs weight, (i.e. the same as the largest bare lead pot practicable.)
2. They are not suitable for large pots because of the great increase in overall dimensions and containment for the vermiculite.
3. They make a very good type A pot.

OTHER EXPERIMENTS

38. Neutron sources in paraffin wax containers are one of the more potent sources of fire in this mode of transport. This problem was overcome by putting the source container supported on a spider into a drum with about 6″ of vermiculite all round. Tests showed that the temperature at the surface of the paraffin wax rose only to 34°C, see figs. 32, 33 and 34.

39. A comparison was made between Mandoval Grade 1 and Mandoval Grade V Vermiculite, fine and coarse respectively. In both cases a drum filled with the material with thermocouples spaced across the diameter was placed in the furnace and heated. The Grade 1 gave the better insulation—it is interesting to note the trend of the graph on this test showing the rise in temperature for some time after withdrawal from the furnace, see fig. 35.

40. Compression tests were carried out on Iroko samples both along the grain and in the weakest direction, i.e. with the rings at 45° to the test piece. The results were 4·1 and ·85 tons per square inch respectively.

STANDARD DESIGN BASED ON EXPERIMENTS

41. To avoid perpetuating the large number of pots at present in existence which are of a large range of sizes, it has been proposed by the Research Group that a family of six pots that may be used as either type A or B depending on the contents and which may travel in a wood liner and steel drum or in a wood liner with two steel drums, be designed. The range of sizes proposed gives from 2″ to 10″ of shielding and a cavity size of $1\frac{1}{4}$″ dia. x $3\frac{7}{8}$″ deep up to 4″ dia. x 8″ deep. Various lead inserts may be used to increase the shielding. The capacity of the pots varies from 220 mc of Co^{60} up to 20,000 curies of Co^{60} or 60 mc of Na^{24} up to 500 curies of Na^{24}. The weight range is 150, 290, 632, 1200, 3280 and 5300 lbs. The first container will be bare lead, the other partly or wholly mild steel clad for handling purposes. It is proposed that the first four be in drums with turned wood inserts and the last two in wood cases.

EXEMPT QUANTITIES OF FISSILE MATERIALS

42. The I.A.E.A. regulations exempt up to 9 grams of Pu^{239} and 16 grams of U^{235} from criticality control and type B packaging on this ground. The British transport authorities have not yet agreed to these limits neither has the I.A.T.A. which does not recognise any exempting limits. Plutonium is, however, liable to type B packaging on the grounds of being a group 1 material of which only 100 micro curies is allowed in a type A package. A very cheap and efficient type B package may be made for these quantities of materials by using a 2″ thick teak or beech shield inside a metal pot, the centre cavity being lined with cadmium. This thickness of wood has been declared safe from neutron interaction for these quantities by the criticality experts. For the carriage of larger quantities of fissile material the metal pot with the 2″ liner may be put into a further 2″ thick teak liner and enclosed in a standard steel drum, it will then be safe from neutron interaction and is a B1 container.

GENERAL CONCLUSIONS

43.
1. With thermal insulation and mechanical protection it is possible to design economic containers to meet the regulations.
2. Hardwood is the most suitable thermal insulator and mechanical protector.
3. A family of containers designed to these principles would cover most of the shielded transport containers in general use.
4. Large containers may be insulated with hardwood.
5. Exempt quantities of fissile materials i.e. 9 grams Pu, 16 grams U^{235} or 16 grams U^{233} may be safely transported in a container to the I.A.T.A. approval requirements by using a container designed on the principles outlined in para. 42.

REFERENCES

1. W. de L. M. Messenger and A. Fairbairn, A.H. & S.B. SR.19 3rd Draft Sub. ref. T.C.A.P./P48 Published May 1962.
2. Experimental measurement at A.E.R.E. using mercury thermometer.
   New Antimonial Lead. Melting Point 312°C Pasty 295°C.
   Remelted Antimonial Lead. Melting Point 315°C Pasty 297°C.
3. Handbook of Chemistry and Physics. Chemical Rubber Publishing Co.
4. Lead in Modern Industry. Lead Industries Association, New York.
5. Timber & Fire Protection. Timber Development Association Limited.
6. Compression Test on Iroko. Test No. 15.

SOURCES OF MATERIALS

Resin bonded wood wool liners supplied by Messrs. Evan Bellhouse, Manchester.
Phenolic Foam supplied by Messrs. Bakelite Ltd.
Lead Pot in Expt. No. 22 manufactured by James Girdler Ltd.
Steel Drum, stock range of Messrs. Todd. Bros.
15 cwt container, manufactured by Messrs. Graviner.
Vermiculite manufactured by Mandoval Ltd.
Hardwood liners manufactured by Elliott Bros., Reading.
Hardwood Case manufactured by Wilmot Packaging, Southampton.
Cedar Wood Case manufactured by Parker Timber Co.. Theale.

PROGRAMME OF TESTS ON ISOTOPE CONTAINERS

SHEET No 1
ISSUE 3

Test No.	Details of Container	Weight lbs	Drawing No	Maximum Furnace temp °C	Duration of Test	Drop test 30 ft	Date of Completion	Object of Test	Remarks
1	Test container with screwed top	25 approx	—	370	—	Not drop tested	—	To observe the effects of heating the container above the melting point of lead (Temperature limited by the capacity of the furnace)	Container failed because of weld fracture due to the dressing of the weld after manufacture X-ray after test showed large void due to expansion and loss of lead
2	Krypton 85 container	14	Design No 0360 B 238696	800	90 mins	Drop tested 20 ft	11 11 60	To observe the effects of heating container above melting point of lead and to check whether or not Krypton gas escaped as a result of the fire test	When end of container was sawn off 30% of lead had transferred from wall cavity to inner space via threaded plug A very gradual gas leak occurred during test which was not detectable at the time
3	Fibreglass container	20 approx	—	—	—	Drop tested 25 ft at A E R E	—	Proposed lightweight type B' container fibreglass tube with lead pot supported by steel spiders in the centre	Satisfactory drop test but subsequent furnace tests on other pots proved that this type would not have sufficient insulation Abandoned
4	Lead filled container with compensating ring	60 approx	—	358	70 mins	Not drop tested	3 8 61	To test the compensating ring at elevated temperatures (Temperature limited by capacity of furnace)	Container leaked from copper gasket on filling hole Pressure thus released and ring found intact when container was sectioned
5	Test container (Radiographed Welds)	56	DH 254656 (Assy A)	370	90 mins	Not drop tested	30 8 61	To observe the effects of heating the container above the melting point of lead (Temperature limited by the capacity of the furnace)	Container failed—mild steel shell fractured X ray after test showed void due to expansion and loss of lead
6	Lead filled container with compensating ring	66 4	DH 254690	786	50 mins	Not drop tested	23 10 61	To test the compensating ring at ele vated temperatures	M S shell intact when removed from furnace although badly distorted Lid which had no ring failed When container was sectioned ring had apparently melted and void was present
7	'U type lead pot R C C wooden box	—	Design No 0353	830	30 mins	Not drop tested	2 11 61	Comparing its resistance to fire against the teak assembly in test (8)	Wooden box completely destroyed Lead pot melted in about 5 mins
8	'U' type lead pot inside teak insulated container	—	Design No 0353 Z 4453	830	30 mins	Not drop tested	3 11 61	To observe the effects of using teak as a thermal insulator on a bare lead pot	Lead pot undamaged when removed from teak liner Max inner temp 97°C
9	'U' type lead pot in Teak, Elm and Iroko liners	—	Design No 0353 Z 4453	800	Elm, Iroko } 30 mins Teak 50 mins	Not drop tested	16 1 62	To compare the use of different types of wood as thermal insulators	Elm liner—Temperature rose very rapidly Iroko liner—maximum temperature 131°C Teak Liner—295°C after 50 minutes in furnace Iroko satisfactory substitute for teak

PROGRAMME OF TESTS ON ISOTOPE CONTAINERS

SHEET No. 2
ISSUE 5

Test No	Details of Container	Weight lbs	Drawing No	Maximum Furnace temp °C	Duration of Test	Drop Test 30 ft	Date of Completion	Object of Test	Remarks
10	Neutron source container (packed with Grade 5 Vermiculite)	—	Design No 0220 R C C Type A5N	850	30 mins	Not drop tested	19 1 62	To observe the effects of using vermiculite as a thermal insulator and to establish the temp. at the centre of the drum (34°C max) normally wax filled inner container	Plywood spider supporting inner container charred to a depth of 2 ins Discoloured to a depth of 3 ins. (Now used as a standard 'B' type container for R C C Neutron source)
11	Test container (normal weld) in Teak shield	56 59	DH 254656 (Assy B) Z 4442	840	60 mins	Drop tested at A W R E Aldermaston before furnace test	30 1 62	To observe the effects of using teak cladding as a thermal insulator	M S shell intact when removed from teak liner Max inner temp recorded after 60 mins was 75°C Container rubber gasket still resilient at end of test
12	M S Shell filled with Vermiculite Grade 1 & 5	—	Z 4442	800	Grade 5 40 mins Grade 1 30 mins	Not drop tested	2 2 62	To compare the insulating properties of Grade 1 and 5 Vermiculite	When M S shell was removed from furnace and allowed to cool, temperature in centre of shell continued to rise Grade 1 was a better insulator
13	Test container (normal weld)	56	DH 254656 (Assy B)	420	105 mins	Not drop tested	21 3 62	To try and establish the temperature at which M S shell failed and, if possible to see how long a temperature of 350°C could be maintained before failure	Furnace doors were opened when container temperature had reached 290 C Failure had occurred and lead was leaking through a slit in the weld approximately 3 ins long
14	Wood wool liner drop test	65	—	—	—	Drop test at W R L 28 ft	10 4 62	To prove the mechanical strength of soft pack and locking ring on 12 ins dia drum	Satisfactory drop test Locking ring still secured lid after test Lead pot inside wood wool liner undamaged after test This pack would be very inexpensive
15	Compression test on 'Iroko' samples (two specimens tested with grain and two against the grain)	—	BS 373 1957	—	—	—	15 6 62	To establish a maximum compressive strength for 'Iroko'	When load was applied at right angles to the grain failure occurred at 1,930 lbs sq in When applied in the direction of grain failure occurred at 9 250 lbs sq in
16	Fibreboard carton (Penetration Test No 3 13 A H S B (S) R 19 Sub Ref T C A P P 48)	—	Design No 0431	—	—	—	4 7 62	To determine damage sustained by the carton and its contents when a test bar (weight 25 lbs) was dropped on to the carton The end of test bar being 3 ft above ground level (See Report Ref No T C A P 52)	The test bar was dropped on 3 faces of the carton and since the distance shielding was not impaired and the inner can was not punctured it was considered that the container had passed the test
17	Plywood drum type—J (Penetration Test No 3 13 A H S B (S) R 19 Sub Ref T C A P P 48)	—	Design No 0411	—	—	—	5 7 62	To determine damage sustained by the Plywood drum when a 25 lb test bar was dropped on to one end of the drum The end of the test bar being 3ft above ground level (See Report on Miscellaneous Penetration Tests)	Dimensions of drum 9 dia × 10 high × $\frac{3}{16}$ thick Drum was completely empty and the centre of the lid was the impact point Test bar passed through lid and also penetrated the base

PROGRAMME OF TESTS ON ISOTOPE CONTAINERS

SHEET No. 3
ISSUE 1

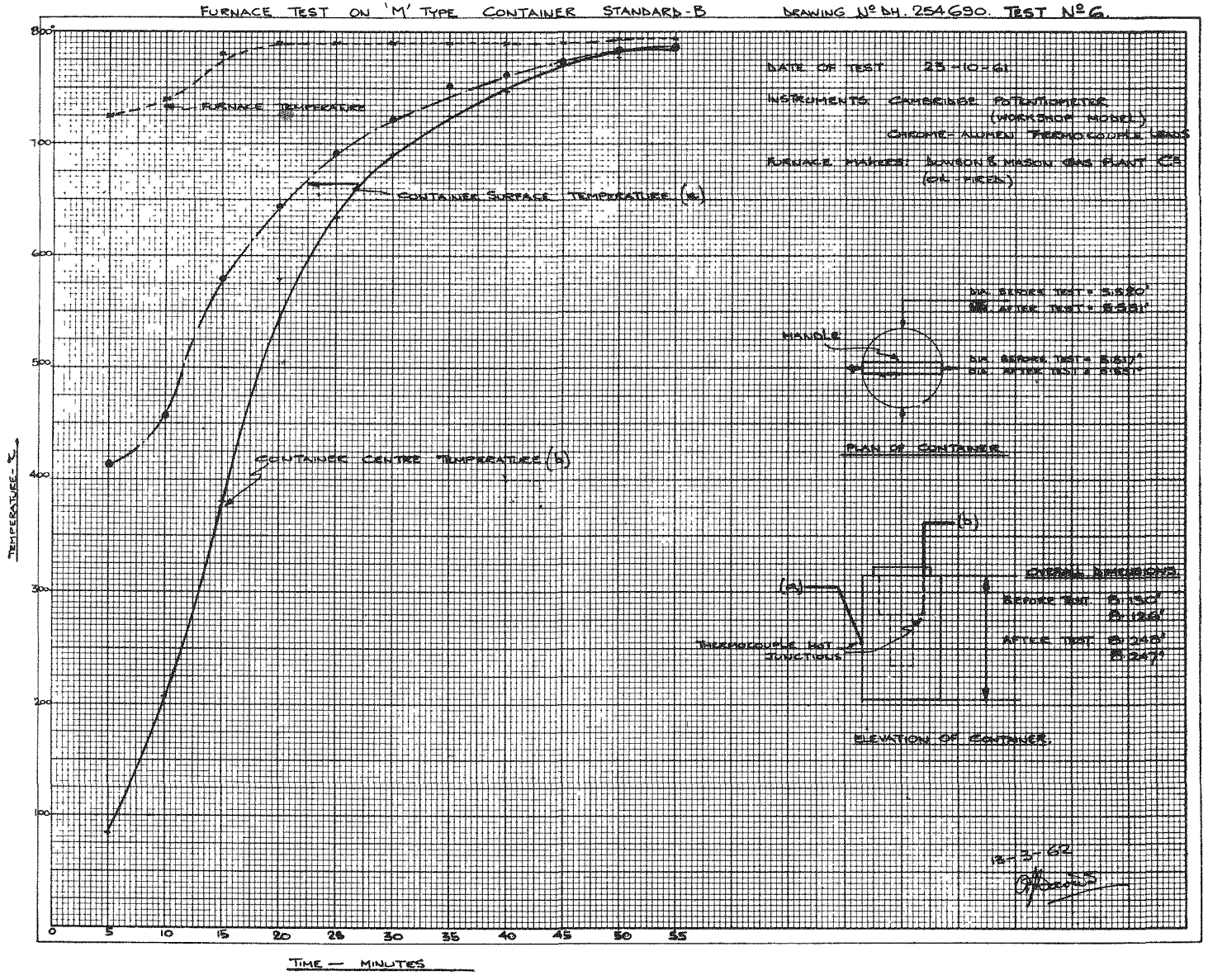
Test No.	Details of Container	Weight lbs.	Drawing No.	Maximum Furnace temp. °C	Duration of Test	Drop Test 30 ft.	Date of Completion	Object of Test	Remarks
18	Plywood sheet $\frac{1}{4}$, thick (Penetration Test No. 3.13 A.H.S.B. (S) R.19 Sub. Ref. T.C.A.P./P.48)	—	—	—	—	—	5.7.62	To observe the effect of dropping a 25 lb. test bar on to a sheet of plywood 9″ square × $\frac{1}{4}$″ thick, the end of the test bar being 3 ft. above ground level. (See Report on Miscellaneous Penetration Tests).	The sheet of plywood was simply supported on all its edges and the test bar was dropped on to its centre. The specimen broke along its centre and across the grain of the outer veneers.
19	Plywood sheet $\frac{3}{8}$, thick. (Penetration Test No. 3.13 A.H.S.B. (S) R.19. Sub. Ref. T.C.A.P./P.48)	—	—	—	—	—	5.7.62	As test No. 18 except that plywood sheet was 9″ square × $\frac{3}{8}$″ thick. (See Report on Miscellaneous Penetration Tests).	The sheet of plywood was simply supported on all its edges and test bar was dropped on to its centre. Test bar punched a hole through the Specimen and carried on through.
20	Isotope box type. LT. (Penetration Test No. 3.13 A.H.S.B. (S) R.19. Sub. Ref. T.C.A.P./P.48)	18	Design No. 0324	—	—	—	5.7.62	To observe the effect of dropping a 25 lb. test bar on isotope box type LT, the end of the bar being 3 ft. above the ground. (See Report on Miscellaneous Penetration Tests).	Dimensions of box 11$\frac{1}{2}$″ square × 12$\frac{1}{2}$″ high × $\frac{1}{2}$″ thick. Box was empty, was placed on firm ground and test bar was dropped on the centre of the lid, one side and its base in turn. Test bar did not penetrate box.
21	Isotope box type W. (Penetration Test No. 3.13 A.H.S.B. (S) R.19. Sub. Ref. T.C.A.P./P.48)	24	Design No. 0357	—	—	—	5.7.62	To observe the effect of dropping a 25 lb. test bar on isotope box type W, the end of the bar being 3 ft. above the ground. (See Report on Miscellaneous Penetration Tests).	Dimensions of Box 18″ long × 13″ wide × 12″ high, sides $\frac{3}{4}$″ thick Deal. Lid and base $\frac{1}{2}$″ plywood. Test conditions as Test No. 20. Test results as Test No. 20.
22	Timber insulated transport container Mk I	150 approx.	Design No. 0665 D.H. 1/297	822	30 mins.	Drop tested At A.W.R.E. Before furnace test *	3.7.6. (Drop test) 11.7.62 (furnace test)	To prove a new standard type 'B' lead pot. Beech liner in inner drum. *Drop test report to be issued by A.W.R.E.	Drop test successful. Slight damage to outer Drum. (Still intact after test). Maximum temperature of bare lead pot during test 86°C. Maximum temperature of lead pot after removal from furnace 110°C.
23	'Iroko' container	115	Z.4442	850	30 mins.	Drop tested at A.W.R.E. before furnace test *	3.7.62 (Drop test) 11.7.62 (furnace test)	(a) To observe the effects of dropping a bare lead pot inside a steel clad wooden liner cavity padded with white felt. (b) To observe the effects of heating a wooden container to 800°C for 30 minutes having removed the mild steel protective shell before the furnace test. *Report to be issued by A.W.R.E.	(a) Overall dimensions of 'M' pot were recorded before and after drop test and there was no change. No apparent damage to pot. (b) Wooden liner charred to depth of 1 inch approximately, White felt was not discoloured. Maximum temperature recorded on the surface of the lead pot 28°C.

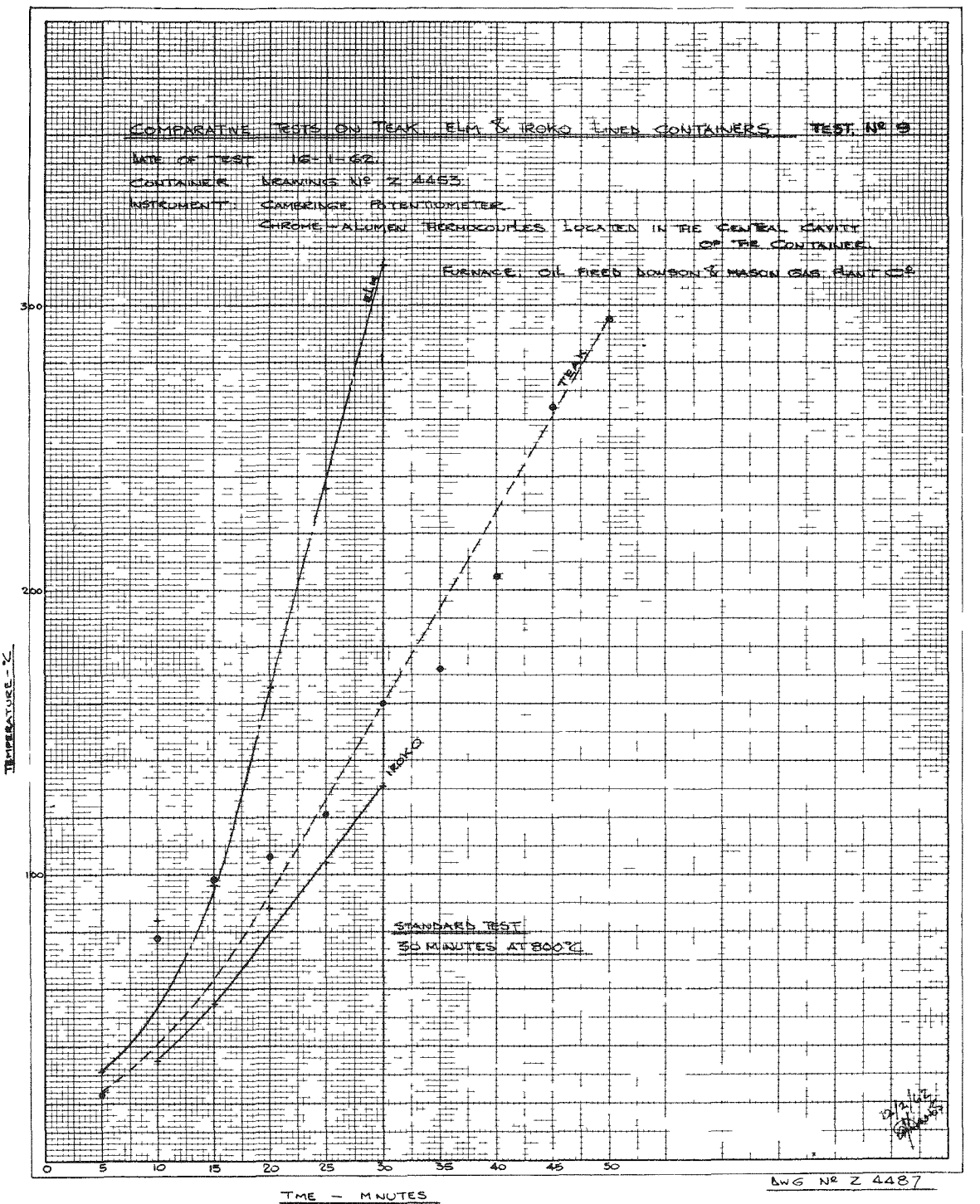
PROGRAMME OF TESTS ON ISOTOPE CONTAINERS

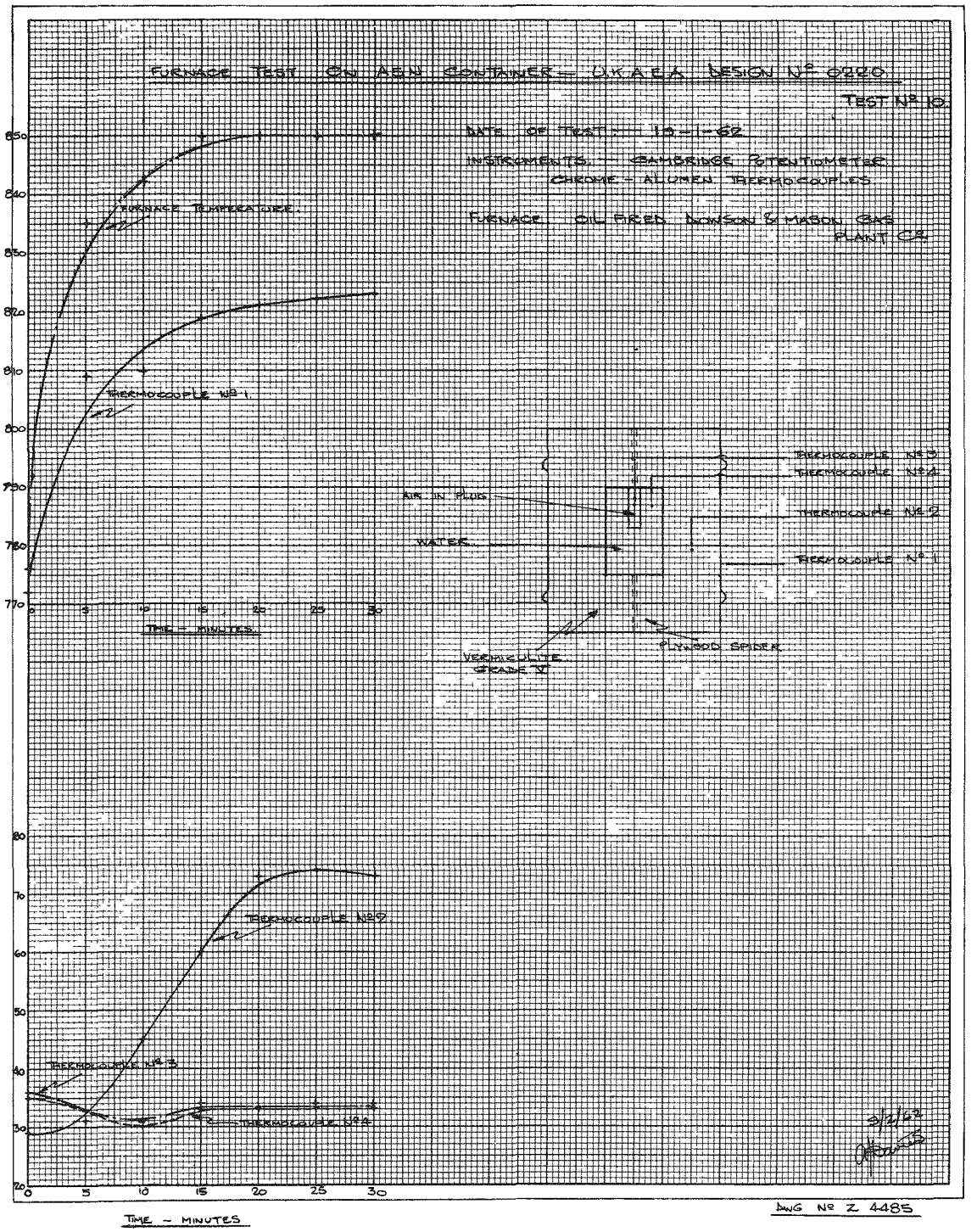
SHEET No. 4
ISSUE 1

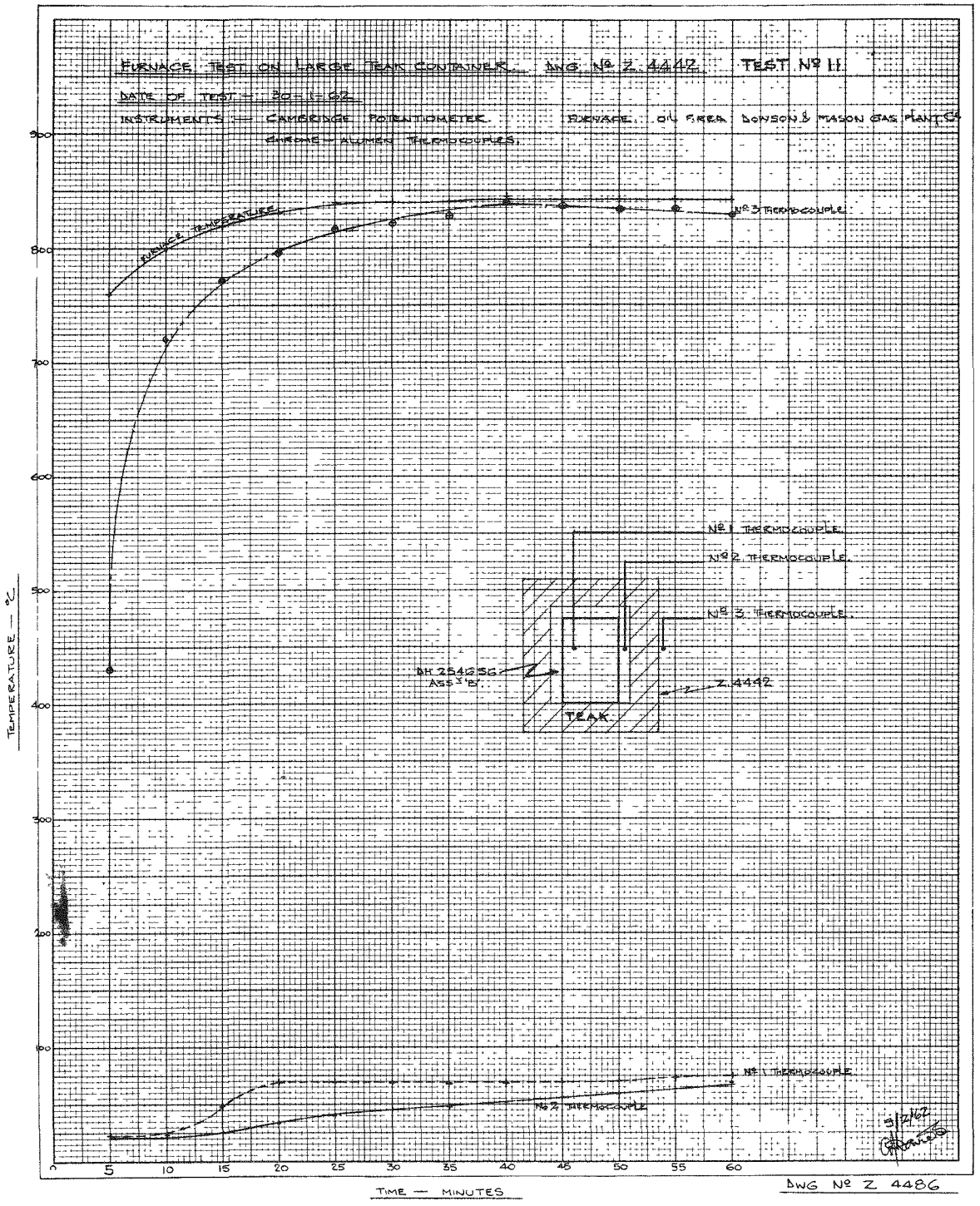
Test No	Details of Container	Weight lbs	Drawing No	Maximum furnace Temp. °C	Duration of Test	Drop test 30 ft	Date of Completion	Object of Test	Remarks
24	Wood wool and Vermiculite insulated container	138	—	820°	30 mins	not drop tested	13 7 62	To observe the effects of using Vermiculite as a thermal insulator and wood wool as the internal packing	Wood wool discoloured at end of test but otherwise intact Maximum temperature of lead pot after 30 minutes = 59°C Temperature was recorded after removal from furnace. Max temperature — 101°C
25	Phenolic resin foam insulated container	—	B 144458 Z 4453	800°	19 mins.	Not drop tested	17 8 62	To observe the effects of using phenolic resin foam DZ 19253 as a thermal insulator	Test had to be discontinued after 19 minutes because of the high temperature recorded Molten lead appeared after 25 minutes
26	'Iroko' liner	115 approx	CH 1/199/2	800°	30 mins	Not drop tested	21 8 62	To compare thermal insulating properties of 2 ins thick of bare Iroko with 3 ins thick of bare Iroko (As Test 23) Also to compare a liner constructed of annular rings with a liner constructed of wooden segments glued together. (As Test 23)	Wooden liner charred to a depth of 1 inch appromixately, white felt was not discoloured Max temperature recorded at the surface of lead pot = 31°C during test Temperature rose to a maximum of 74°C after removal from furnace

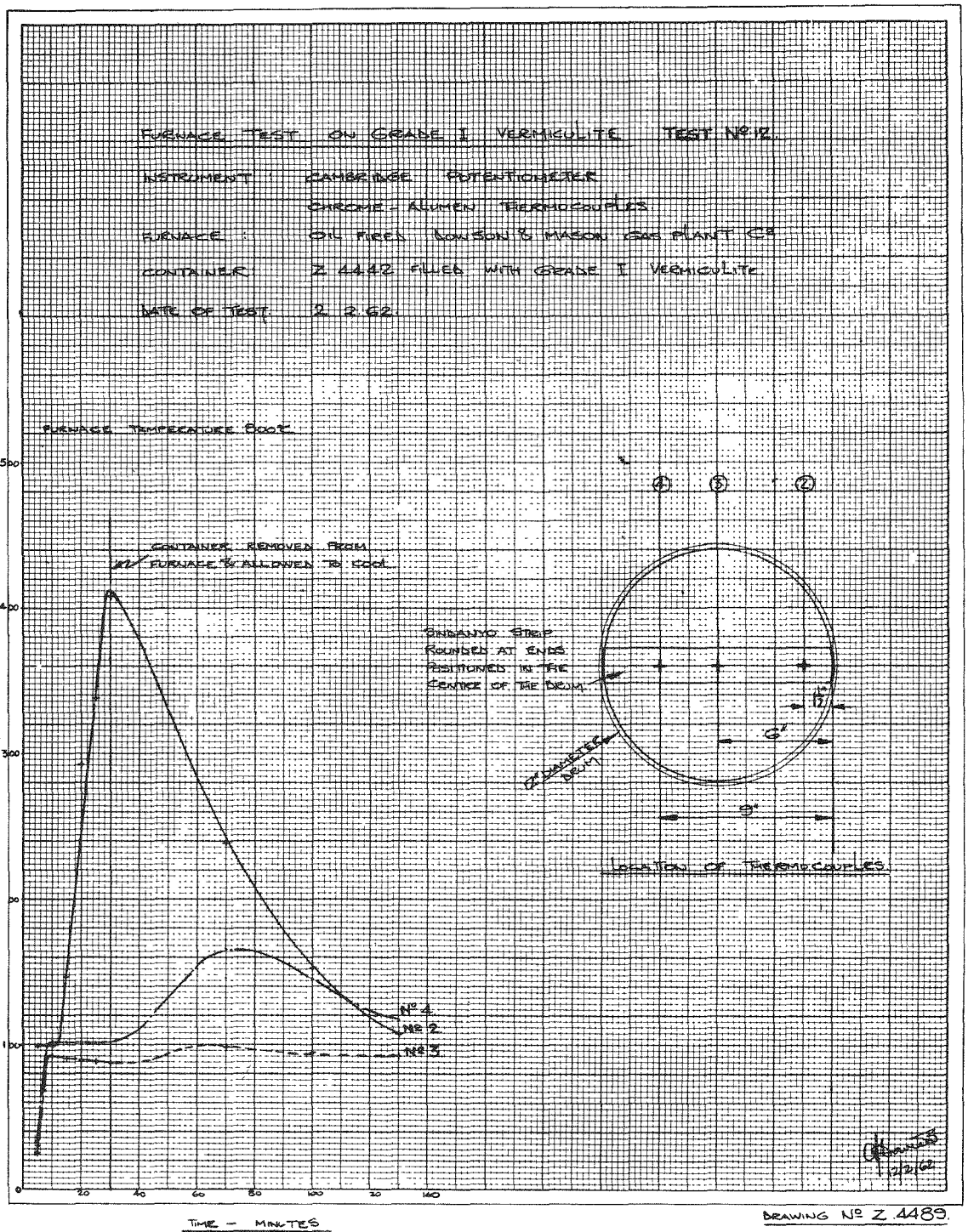
FURNACE TEST ON 'M' TYPE CONTAINER STANDARD-B DRAWING Nº DH. 254690. TEST Nº 6.

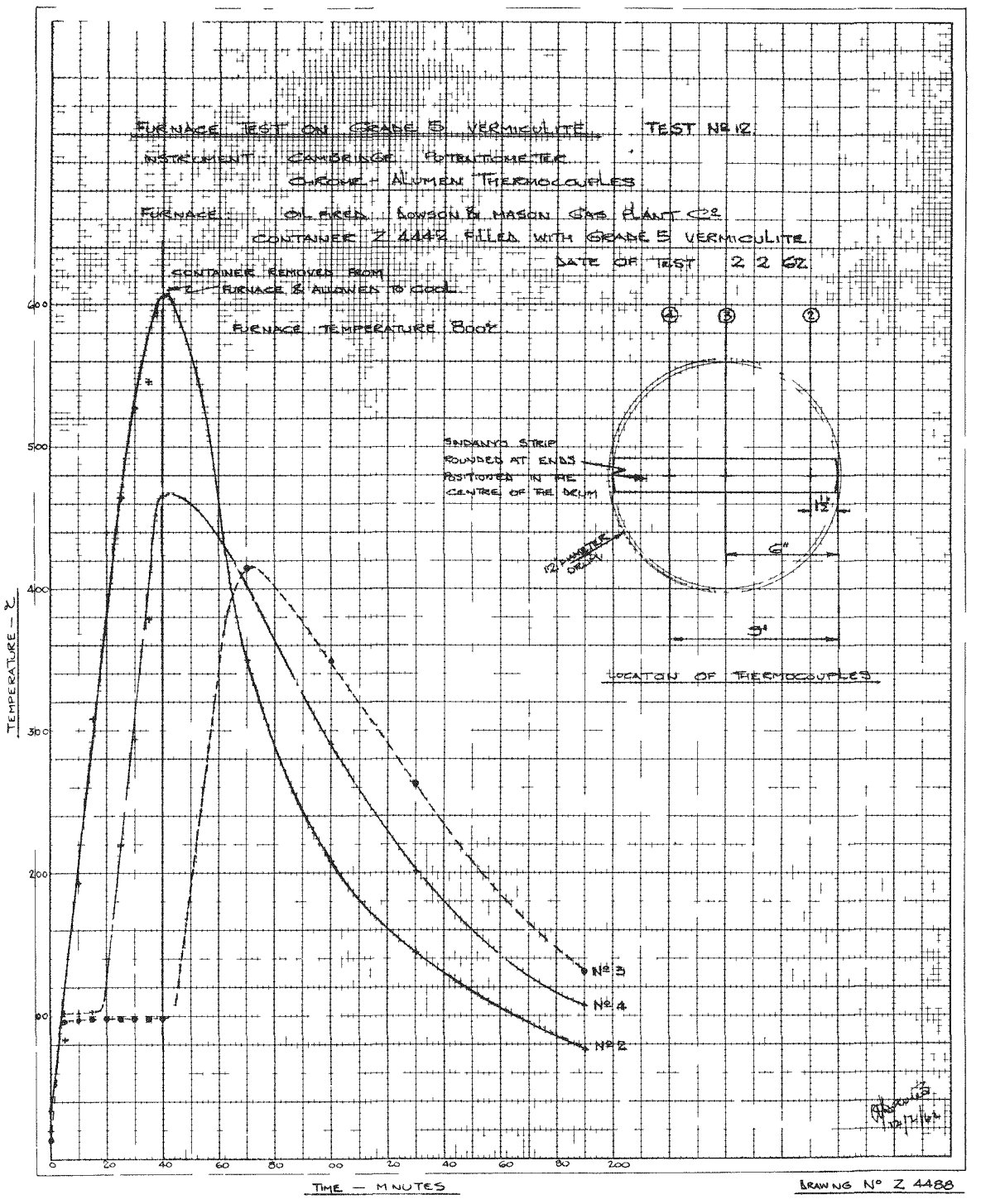



COMPARATIVE TESTS ON TEAK, ELM & IROKO LINED CONTAINERS. TEST. Nº 9
DATE OF TEST. 16-11-62.
CONTAINER. DRAWINGS Nº Z 4455.
INSTRUMENT. CAMBRIDGE POTENTIOMETER.
CHROME-ALUMEN THERMOCOUPLES LOCATED IN THE CENTRAL CAVITY OF THE CONTAINER.
FURNACE. OIL FIRED DOWSON & MASON GAS PLANT Co.
ELM
TEAK
IROKO
STANDARD TEST
50 MINUTES AT 800°C
TEMPERATURE - °C
TIME - MINUTES
0
5
10
15
20
25
30
35
40
45
50
100
200
300
DWG Nº Z 4487

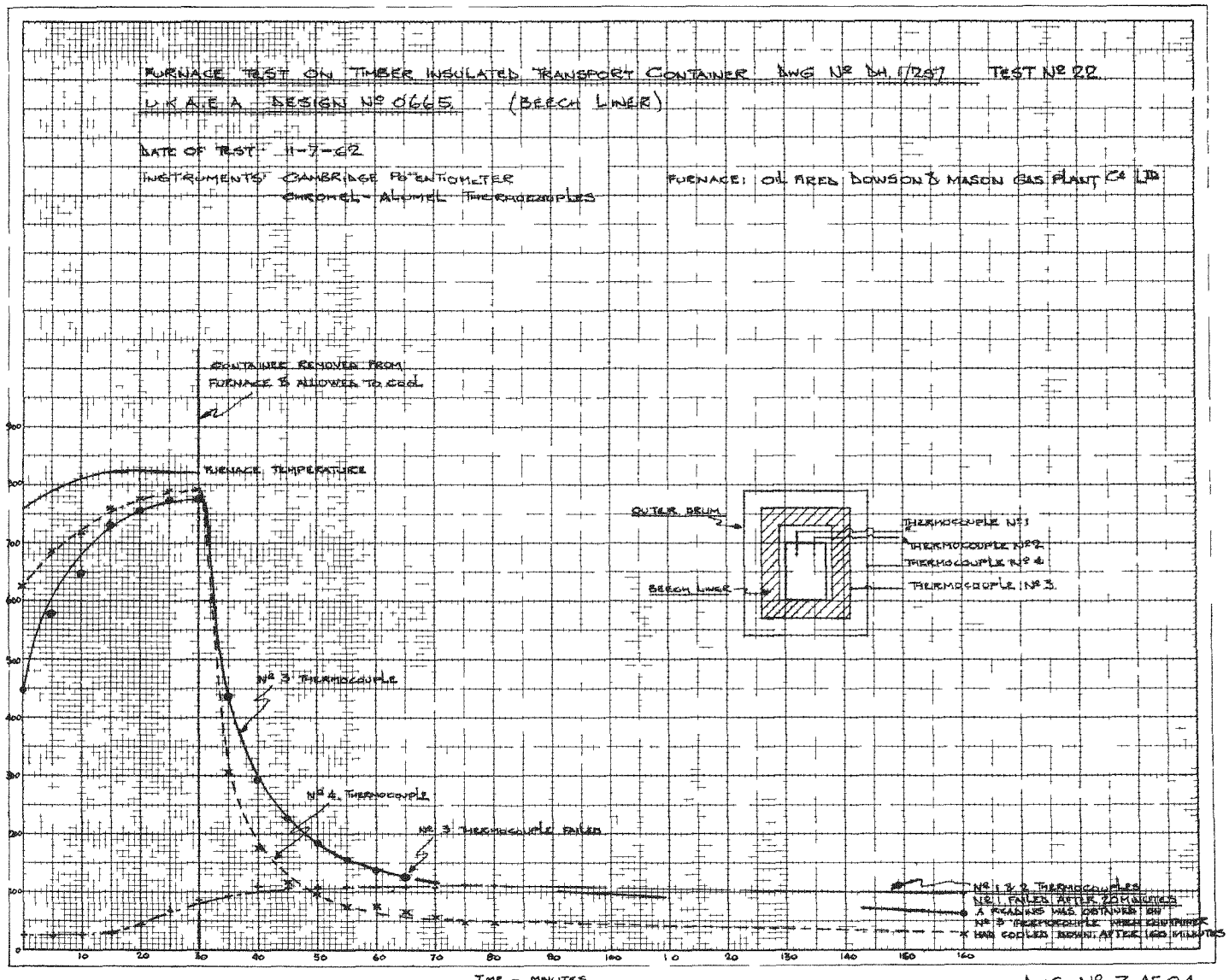

FURNACE TEST ON AEW CONTAINER — U.K.A.E.A. DESIGN Nº 02220.
TEST Nº 10.
DATE OF TEST :- 10-1-62
INSTRUMENTS :- CAMBRIDGE POTENTIOMETER.
CHROME - ALUMEN THERMOCOUPLES
FURNACE OIL FIRED. DOWSON & MASON GAS PLANT CO.
TEMPERATURE - °C
FURNACE TEMPERATURE.
THERMOCOUPLE WB 1
TIME - MINUTES.
THERMOCOUPLE Nº5
THERMOCOUPLE Nº4
AIR IN PLUG
THERMOCOUPLE Nº2
WATER
THERMOCOUPLE Nº1
VERMICULITE GRADE 'M'
PLYWOOD SPIDER
THERMOCOUPLE Nº3
THERMOCOUPLE Nº4
5/2/62
DWG Nº Z 4485

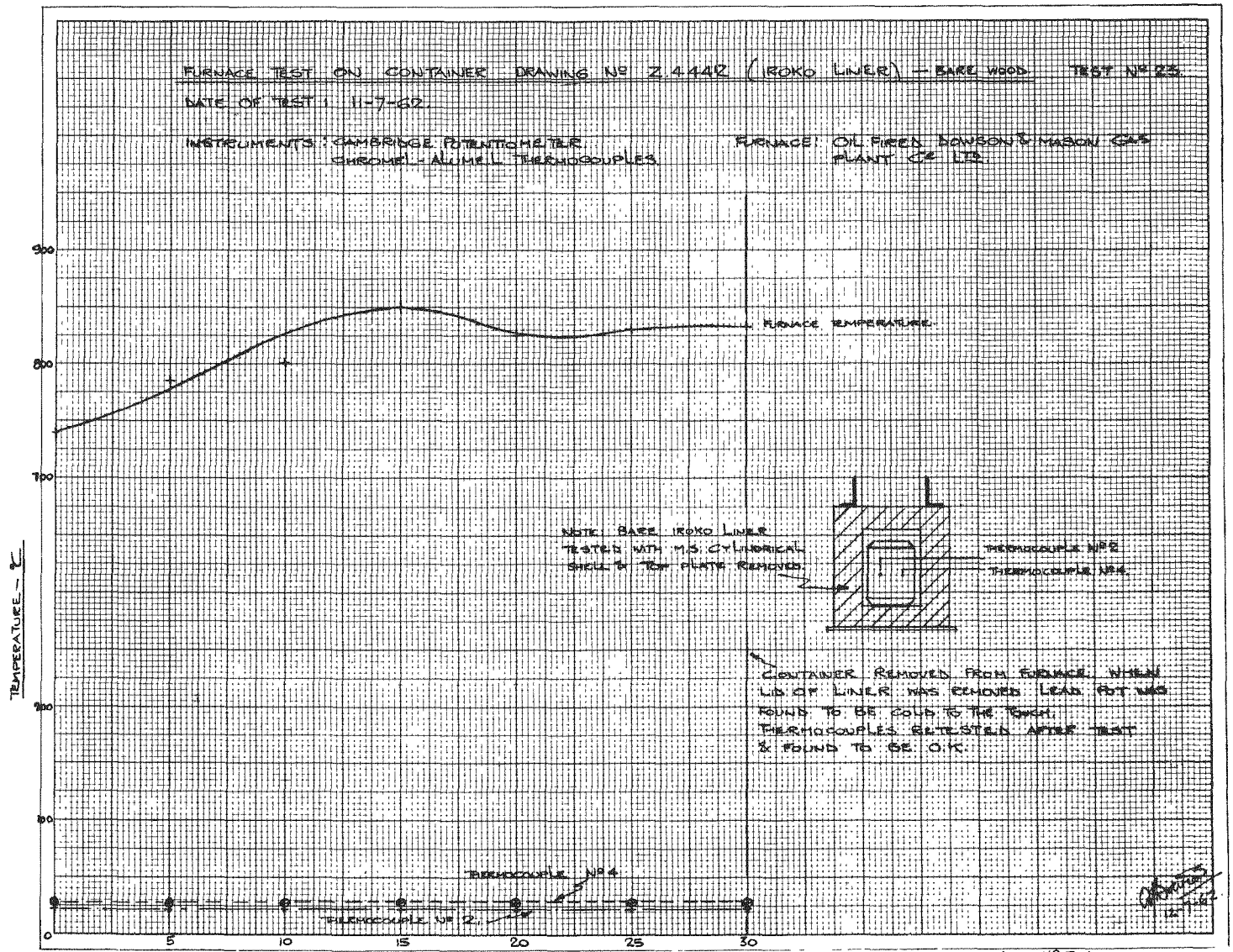

FURNACE TEST ON LARGE TEAK CONTAINER. DWG Nº Z 4412. TEST Nº 11.
DATE OF TEST :- 20-1-62.
INSTRUMENTS :- CAMBRIDGE POTENTIOMETER. FURNACE. OIL FIRED. DOWSON & MASON GAS PLANT CO
CHROME-ALUMEL THERMOCOUPLES.
FURNACE TEMPERATURE
Nº 3 THERMOCOUPLE
Nº 1 THERMOCOUPLE.
Nº 2 THERMOCOUPLE.
Nº 3 THERMOCOUPLE.
DH 2546SG
ASS'Y 'B'.
Z.4412
TEAK
Nº 1 THERMOCOUPLE
Nº 2 THERMOCOUPLE
TEMPERATURE — °C
TIME — MINUTES
DWG Nº Z 4486


FURNACE TEST ON GRADE I VERMICULITE TEST Nº 12.
INSTRUMENT CAMBRIDGE POTENTIOMETER
CHROME - ALUMEN THERMOCOUPLES
FURNACE OIL FIRED LOWSON & MASON (SAS PLANT Co
CONTAINER Z 4442 FILLED WITH GRADE I VERMICULITE
DATE OF TEST 2.2.62.
FURNACE TEMPERATURE ROOT
CONTAINER REMOVED FROM FURNACE & ALLOWED TO COOL
TEMPERATURE — °C
TIME — MINUTES
Nº 4
Nº 2
Nº 3
SWAN'S STRIP ROUNDED AT ENDS POSITIONED IN THE CENTRE OF THE DRUM
GALVANISED DRUM
LOCATION OF THERMOCOUPLES
DRAWING Nº Z 4489.

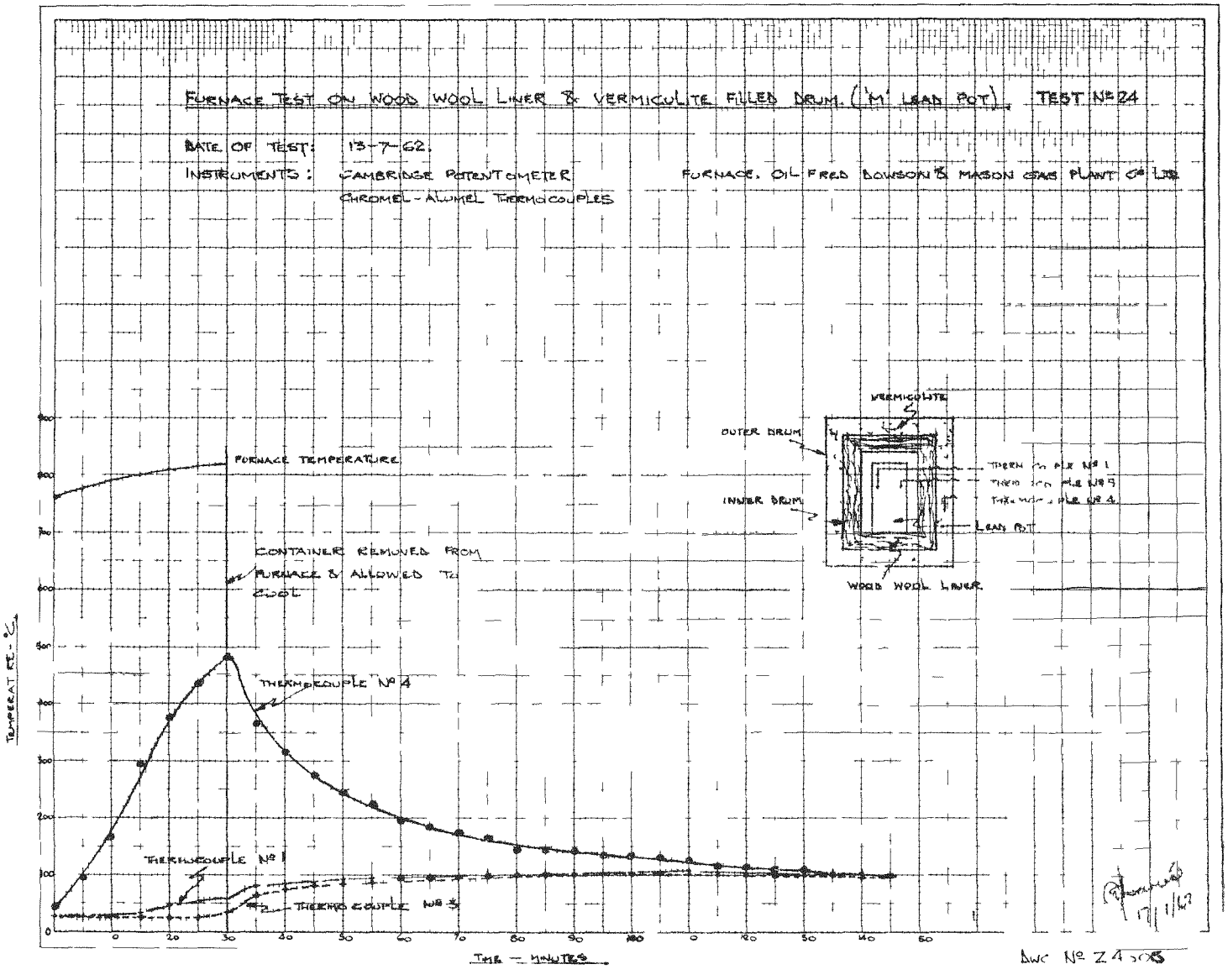

FURNACE TEST ON GRADE 5 VERMICULITE
TEST No 12.
INSTRUMENT - CAMBRIDGE POTENTIOMETER.
CHROME + ALUMEN THERMOCOUPLES
FURNACE - OIL FIRED. LOWSON & MASON GAS PLANT Co.
CONTAINER Z 4442 FILLED WITH GRADE 5 VERMICULITE.
DATE OF TEST 2 2 62.
CONTAINER REMOVED FROM FURNACE & ALUMEN TO COOL.
FURNACE TEMPERATURE BOOST.
SINDANYO STRIP ROUNDED AT ENDS POSITIONED IN THE CENTRE OF THE DRUM
12" DIAMETER DRUM
12"
6"
3"
LOCATION OF THERMOCOUPLES
TEMPERATURE - °C
TIME - MINUTES
No 3
No 4
No 2
DRAWING No Z 4488

FURNACE TEST ON CONTAINER, DRAWING No. LH 254656 – ASSEMBLY 'B'. TEST No. 13.
(TESTED TO DESTRUCTION.)
DATE OF TEST 21-3-62.
FURNACE: SIEMEN & SCHUCKERT (HORIZONTAL)
INSTRUMENTS: CAMBRIDGE POTENTIOMETERS
CHROMEL-ALUMEL THERMOCOUPLES.
HONEY WELL TEMPERATURE RECORDER.
FURNACE TEMPERATURE.
THERMOCOUPLE No. 2.
THERMOCOUPLE No. 3.
THERMOCOUPLE (No. 2.) = HONEYWELL TEMPERATURE RECORDER
CONTAINER DRAWING ASSY. B
THERMOCOUPLE No. 2
THERMOCOUPLE No. 3
SECTION OF THERMOCOUPLES.
TEMPERATURE — °C
TIME — MINUTES
FURNACE DOOR OPENED
FURNACE DOOR CLOSED
FURNACE DOOR OPENED
FURNACE DOOR CLOSED
FURNACE DOOR OPENED
SURFACE OF CONTAINER FOR FIRST TIME WAS LOOKING RED
0
10
20
30
40
50
60
70
80
90
100
110
200
300
400
500


FURNACE TEST ON TIMBER INSULATED TRANSPORT CONTAINER DWG Nº DH 1/267 TEST Nº 22
U.K.A.E.A. DESIGN Nº 0665 (BEECH LINER)
DATE OF TEST 11-7-62
INSTRUMENTS CAMBRIDGE POTENTIOMETER
CHROMEL-ALUMEL THERMOCOUPLES
FURNACE: OIL FIRED DOWSON & MASON GAS PLANT Co LTD
CONTAINER REMOVED FROM FURNACE & ALLOWED TO COOL
FURNACE TEMPERATURE
Nº 3 THERMOCOUPLE
Nº 4 THERMOCOUPLE
Nº 3 THERMOCOUPLE FAILED
OUTER DRUM
BEECH LINER
THERMOCOUPLE Nº 1
THERMOCOUPLE Nº 2
THERMOCOUPLE Nº 4
THERMOCOUPLE Nº 3
Nº 1 & 2 THERMOCOUPLES
Nº 1 FAILED AFTER 204 MINUTES
A READING WAS OBTAINED ON
Nº 3 THERMOCOUPLE WHEN CONTAINER
HAD COOLED DOWN AFTER 160 MINUTES
TEMPERATURE °C
TIME - MINUTES
DWG Nº Z 4504


FURNACE TEST ON CONTAINER DRAWING Nº Z 4442 (IROKO LINER) — BARE WOOD. TEST Nº 23.
DATE OF TEST: 11-7-62.
INSTRUMENTS: CAMBRIDGE POTENTIOMETER. CHROMEL - ALUMEL THERMOCOUPLES.
FURNACE: OIL FIRED. DOWSON & MASON GAS PLANT CO LTD.
TEMPERATURE — °C
900
800
700
200
100
0
5
10
15
20
25
30
FURNACE TEMPERATURE.
NOTE: BARE IROKO LINER TESTED WITH M.S. CYLINDRICAL SHELL & TOP PLATE REMOVED.
THERMOCOUPLE Nº 2
THERMOCOUPLE Nº 4
CONTAINER REMOVED FROM FURNACE. WHEN LID OF LINER WAS REMOVED LEAD WAS FOUND TO BE COLD TO THE TOUCH. THERMOCOUPLES RE-TESTED AFTER TEST & FOUND TO BE O.K.
THERMOCOUPLE Nº 4.
THERMOCOUPLE Nº 2.

DWG Nº Z 4505


FURNACE TEST ON WOOD WOOL LINER & VERMICULITE FILLED DRUM. ('M' LEAD POT) TEST Nº 24
DATE OF TEST: 13-7-62.
INSTRUMENTS: CAMBRIDGE POTENTIOMETER
CHROMEL-ALUMEL THERMOCOUPLES
FURNACE. OIL FIRED BOWSON & MASON GAS PLANT Co LTD
VERMICULITE
OUTER DRUM
INNER DRUM
LEAD POT
WOOD WOOL LINER
FURNACE TEMPERATURE
CONTAINER REMOVED FROM FURNACE & ALLOWED TO COOL
THERMOCOUPLE Nº 4
THERMOCOUPLE Nº 1
THERMO COUPLE Nº 3
TEMPERATURE - °C
TIME - MINUTES
AWC Nº Z 4 5005

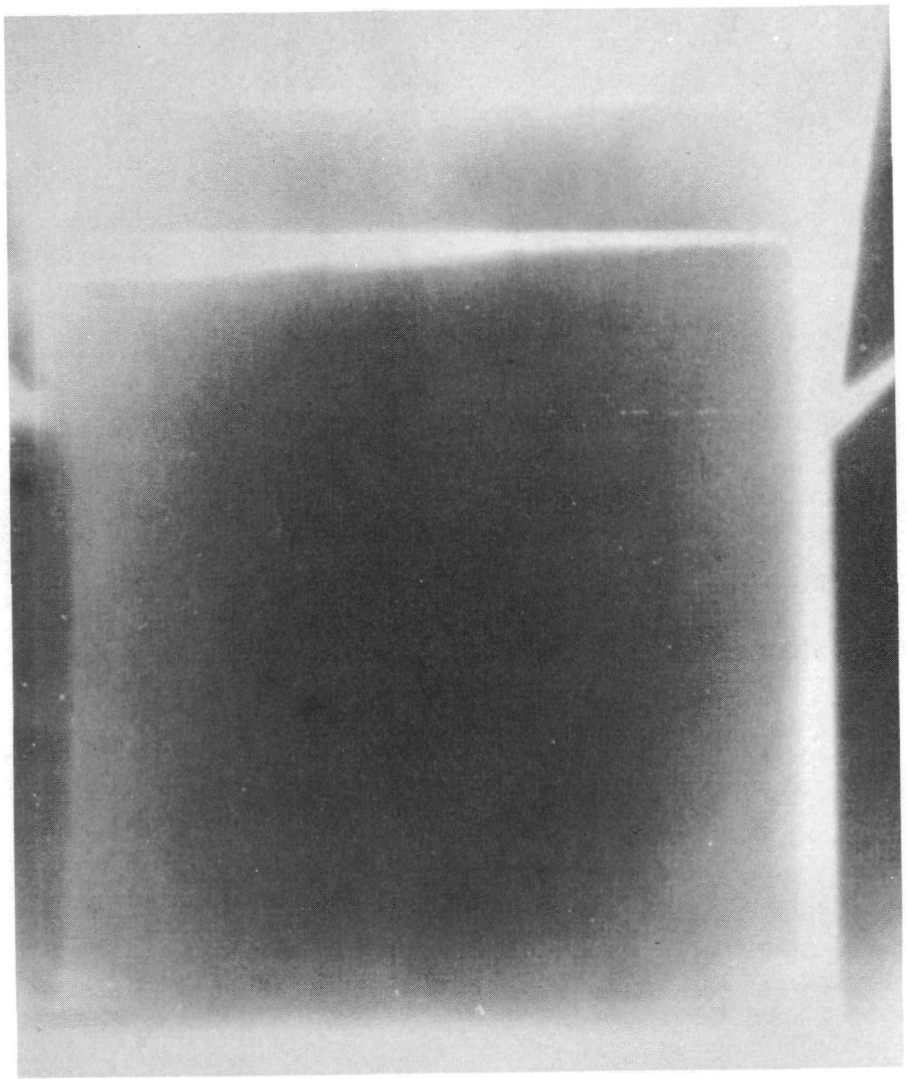


Fig. 1

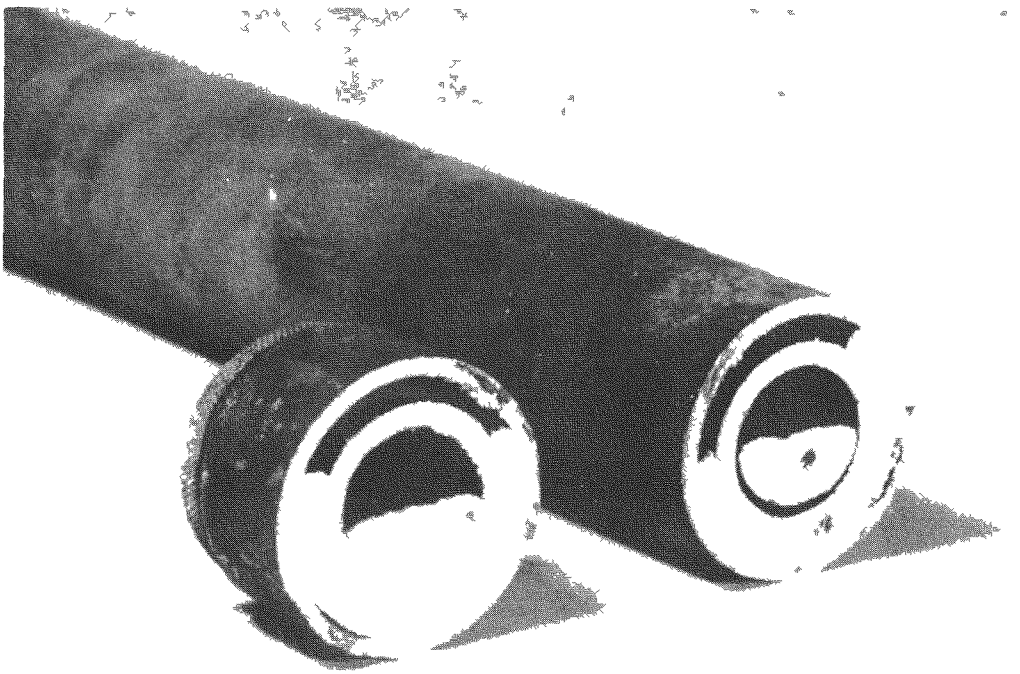


Fig. 2

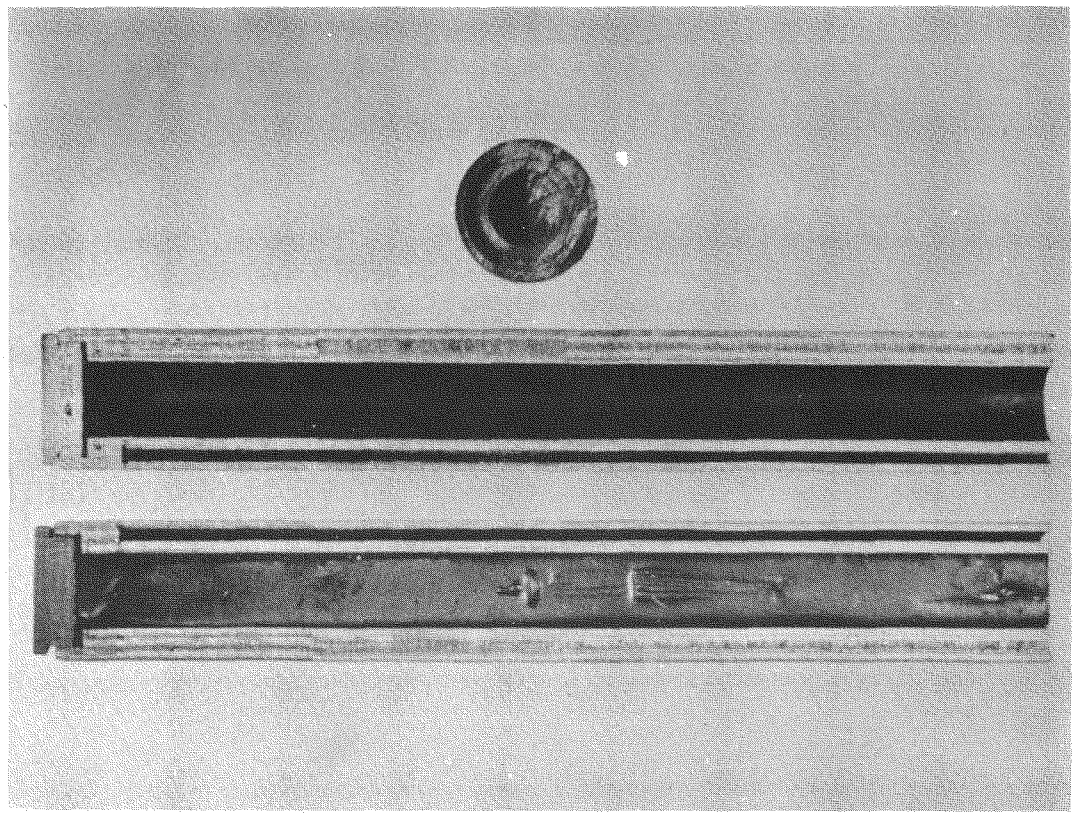


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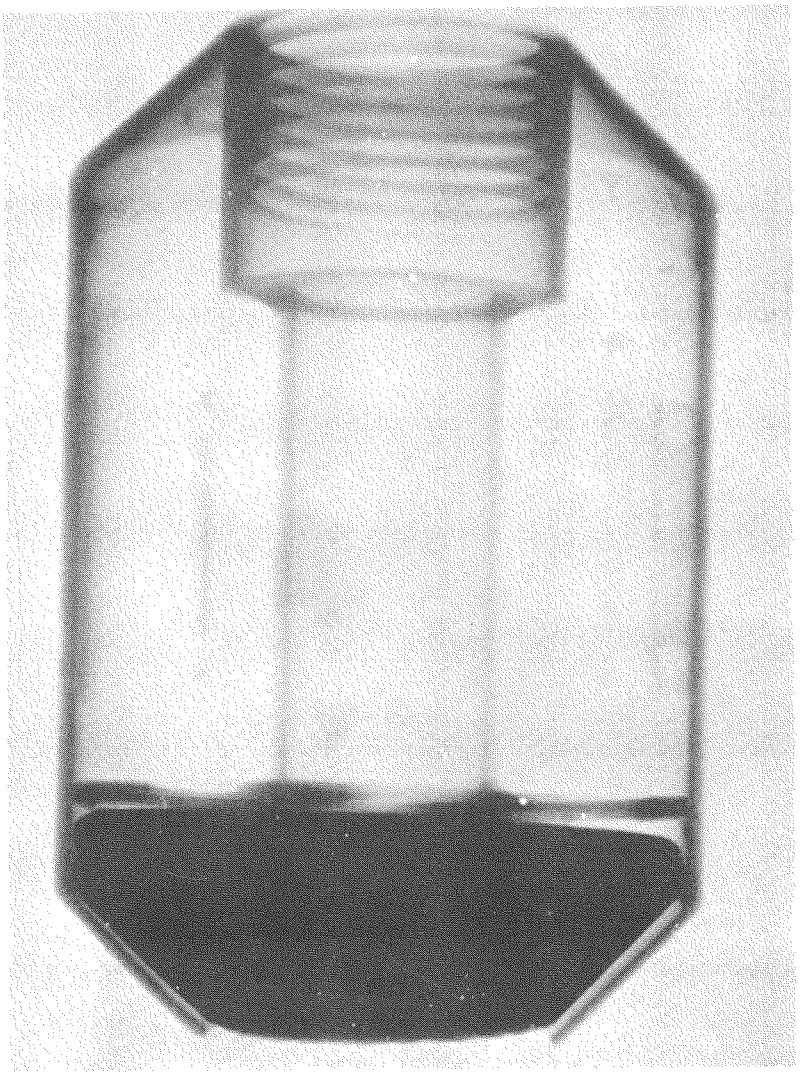


Fig. 4



Fig. 5

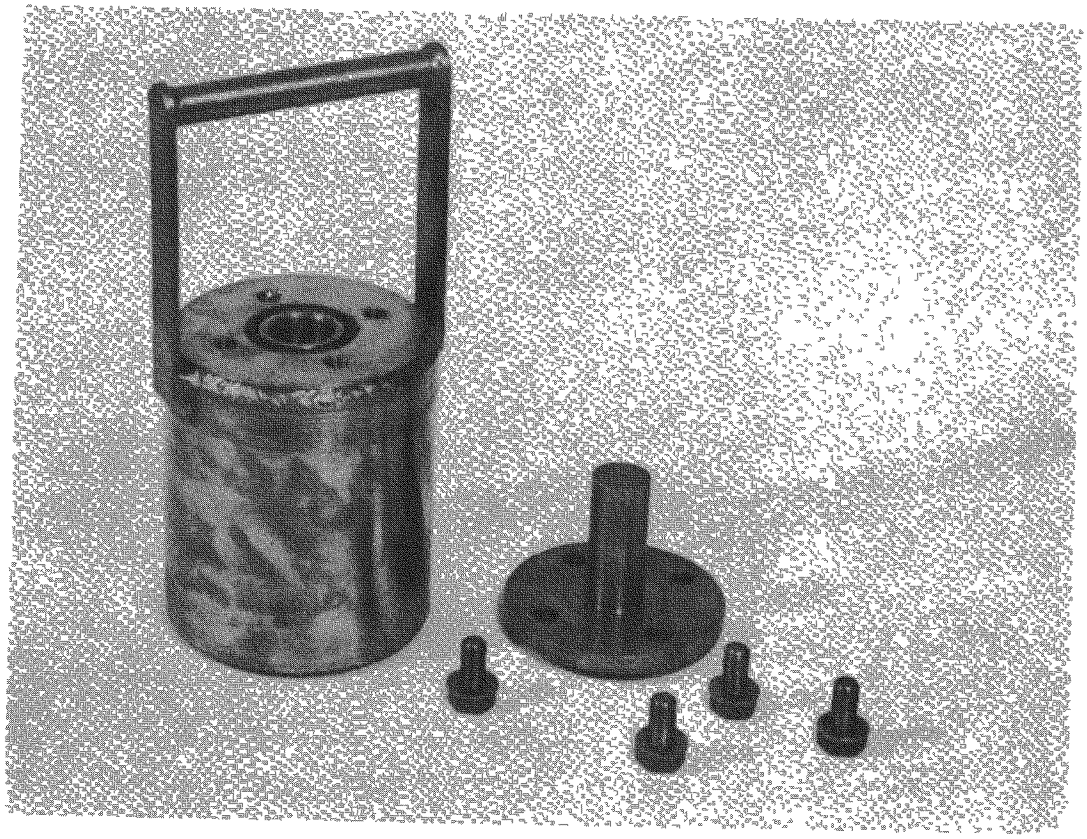


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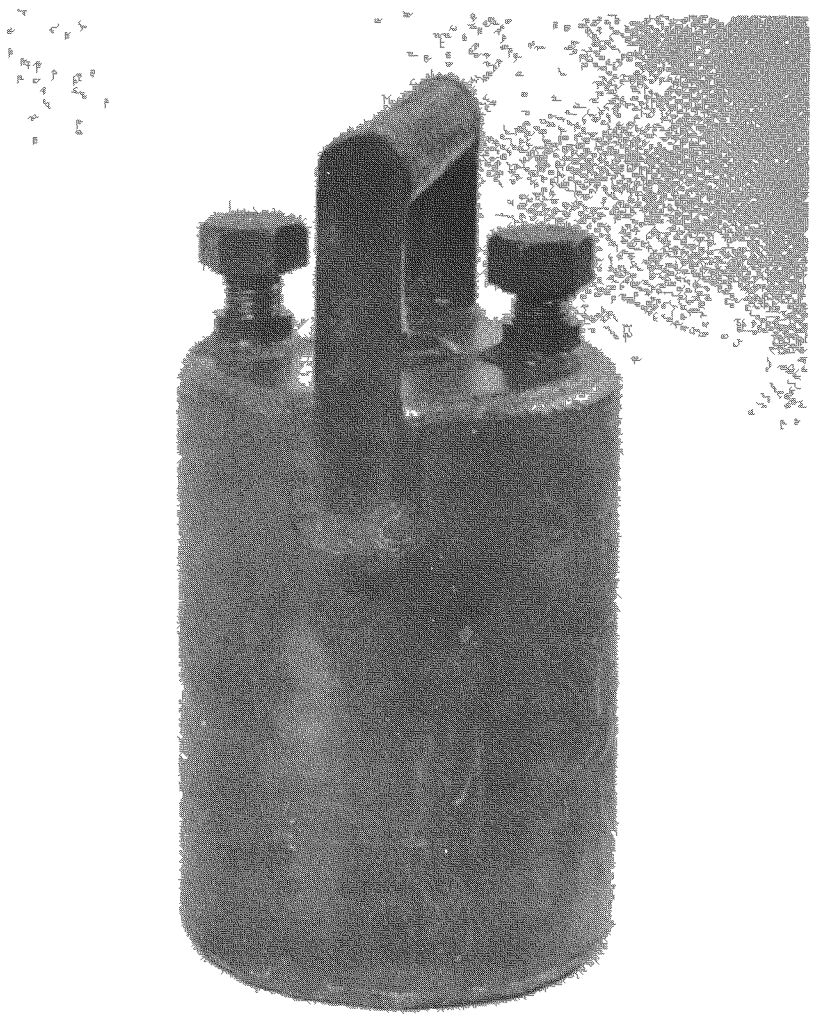


Fig. 7

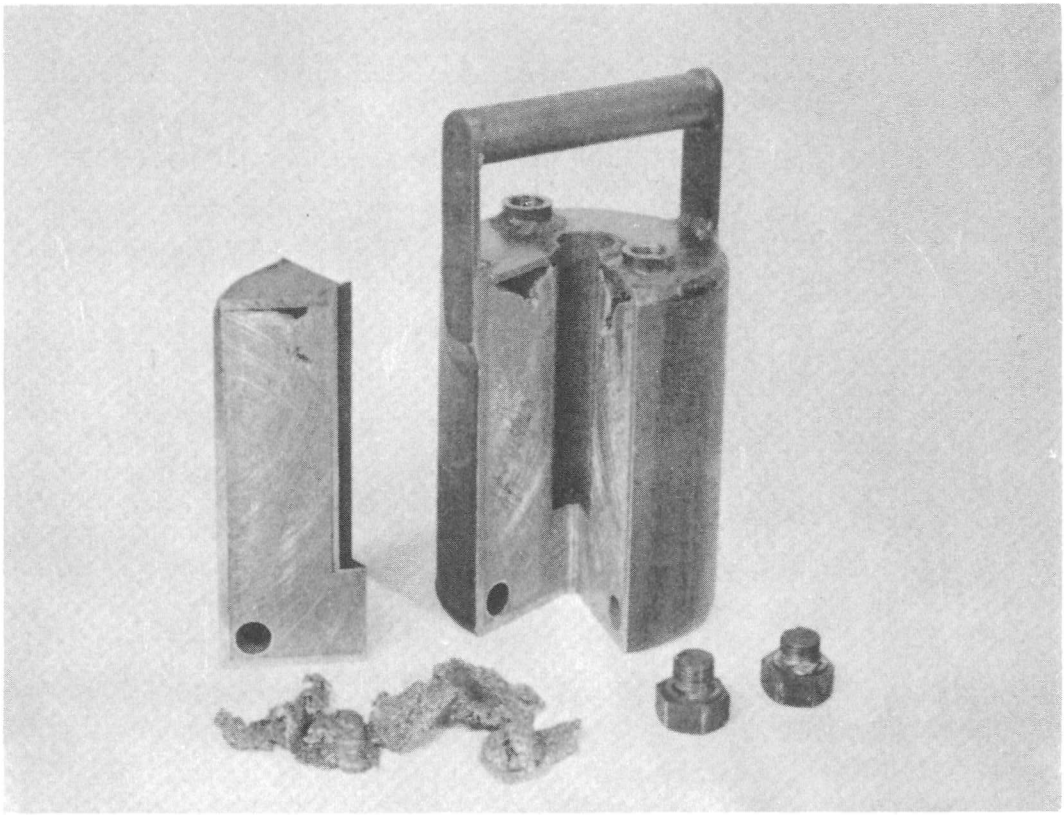


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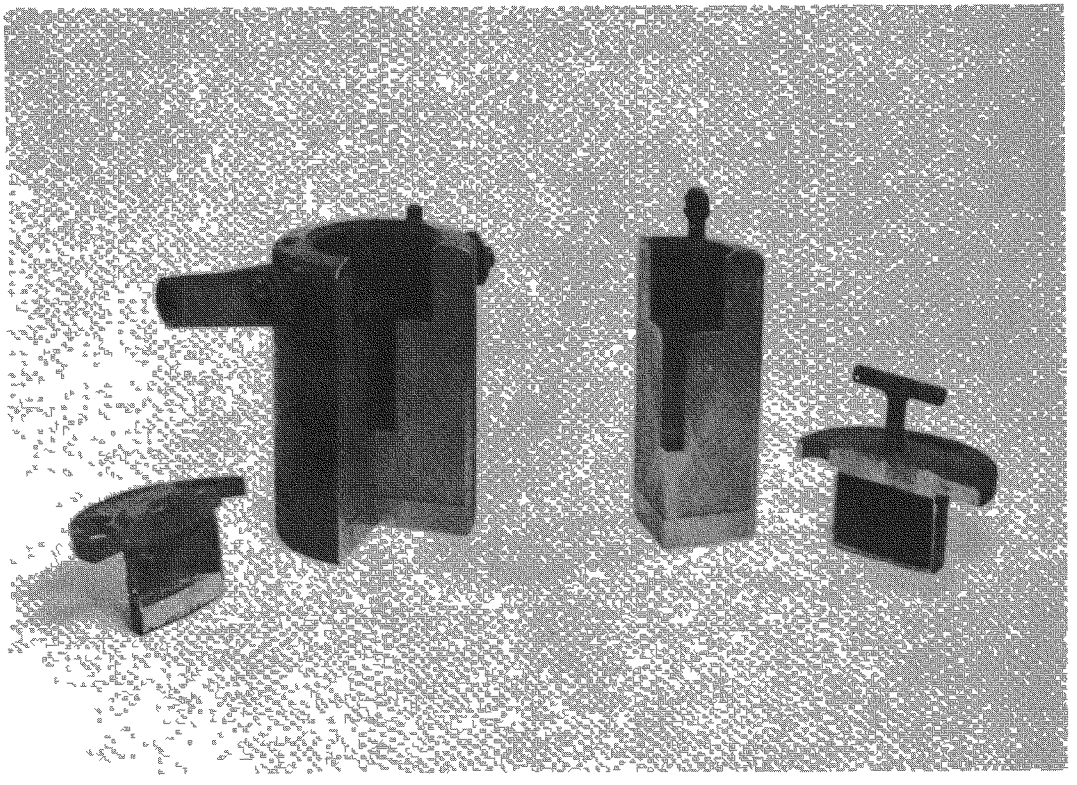


Fig. 9

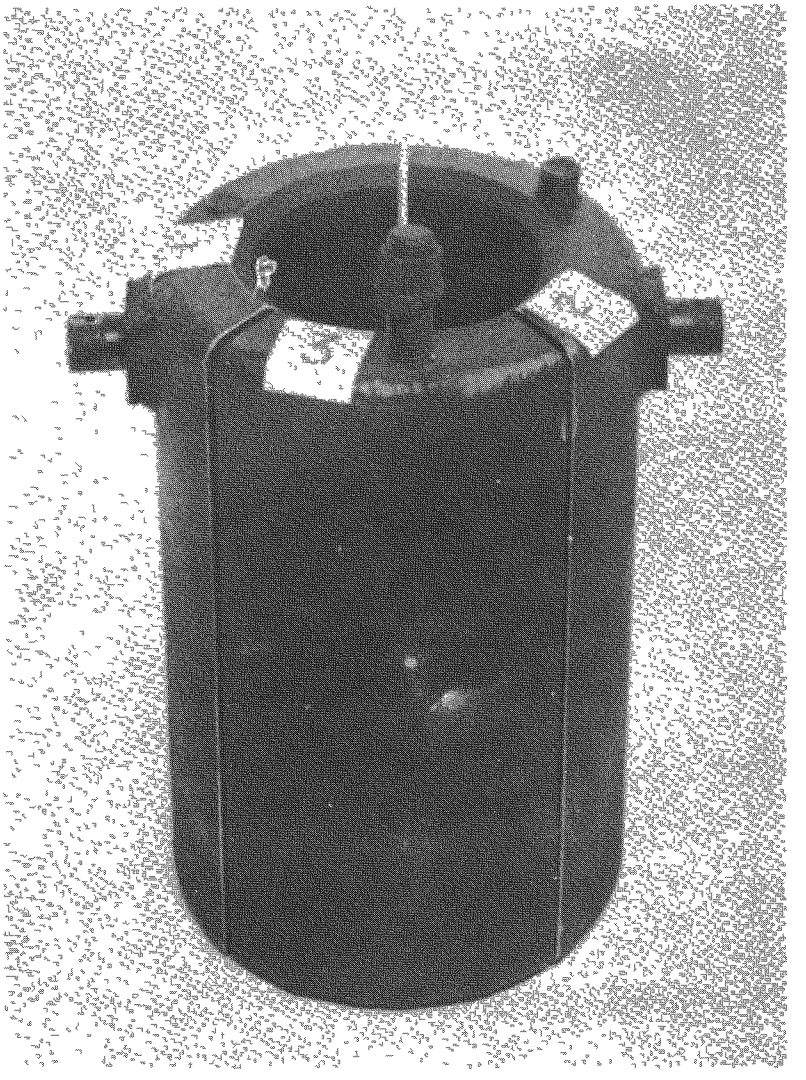


Fig. 10

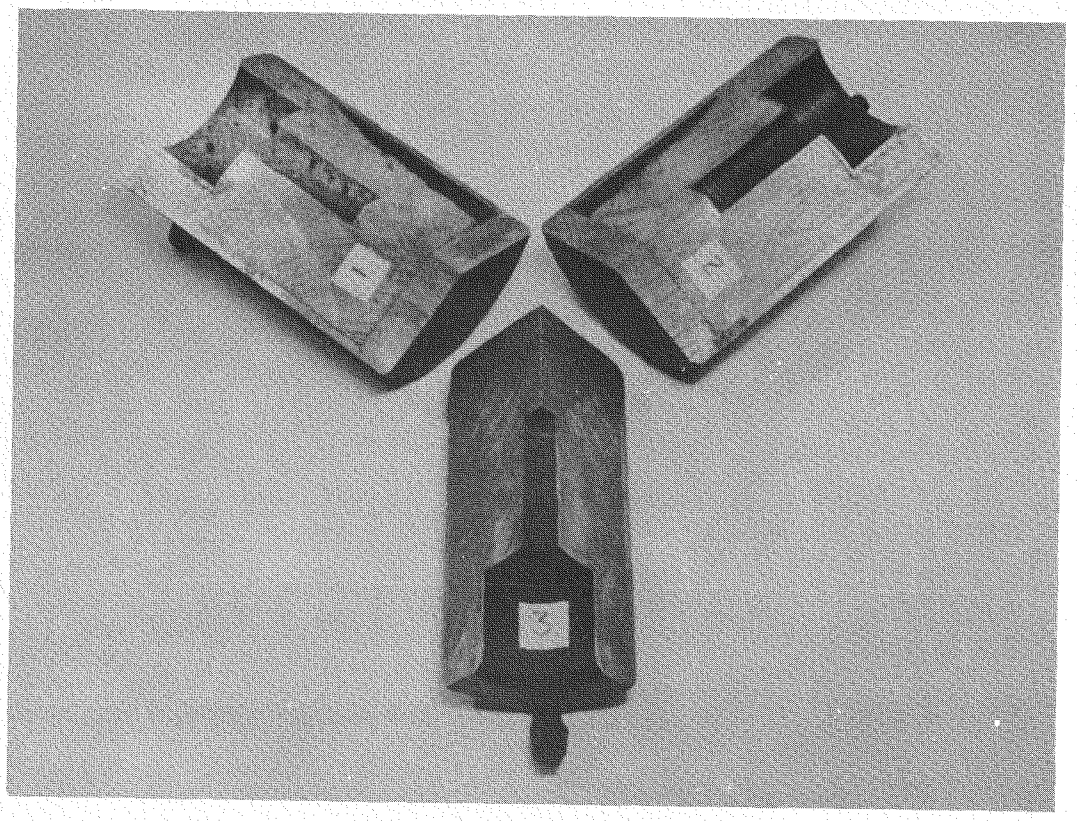


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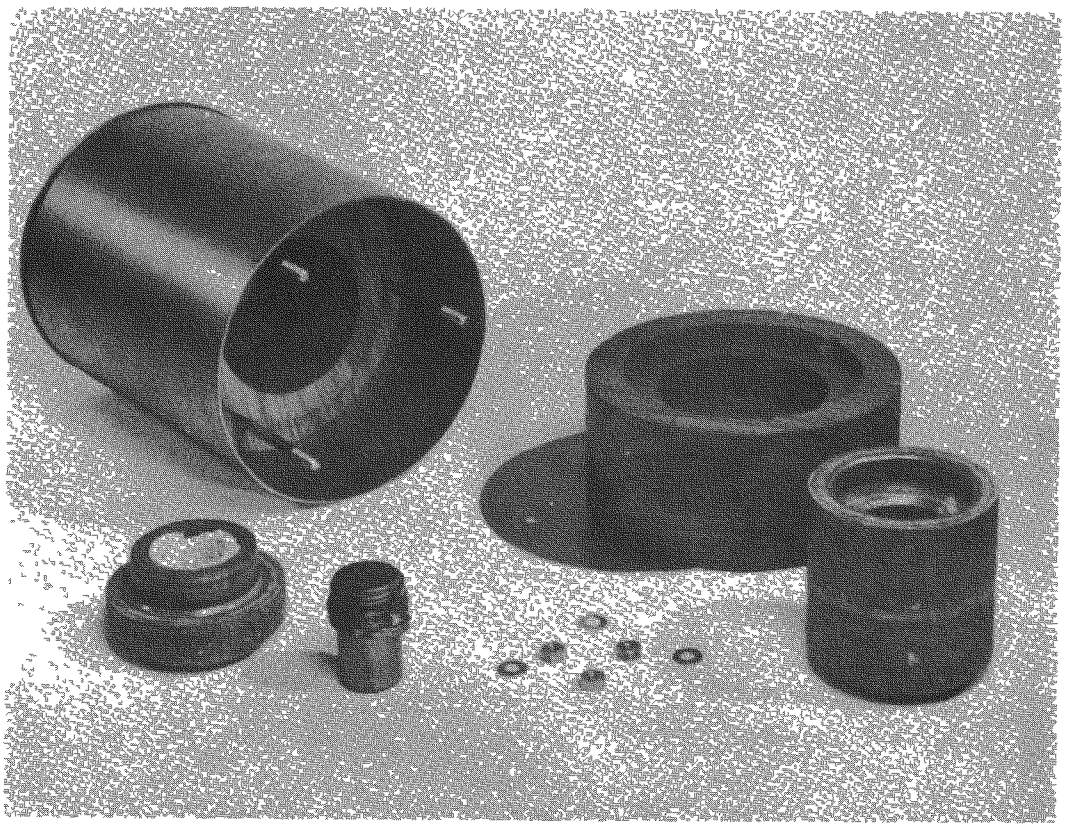


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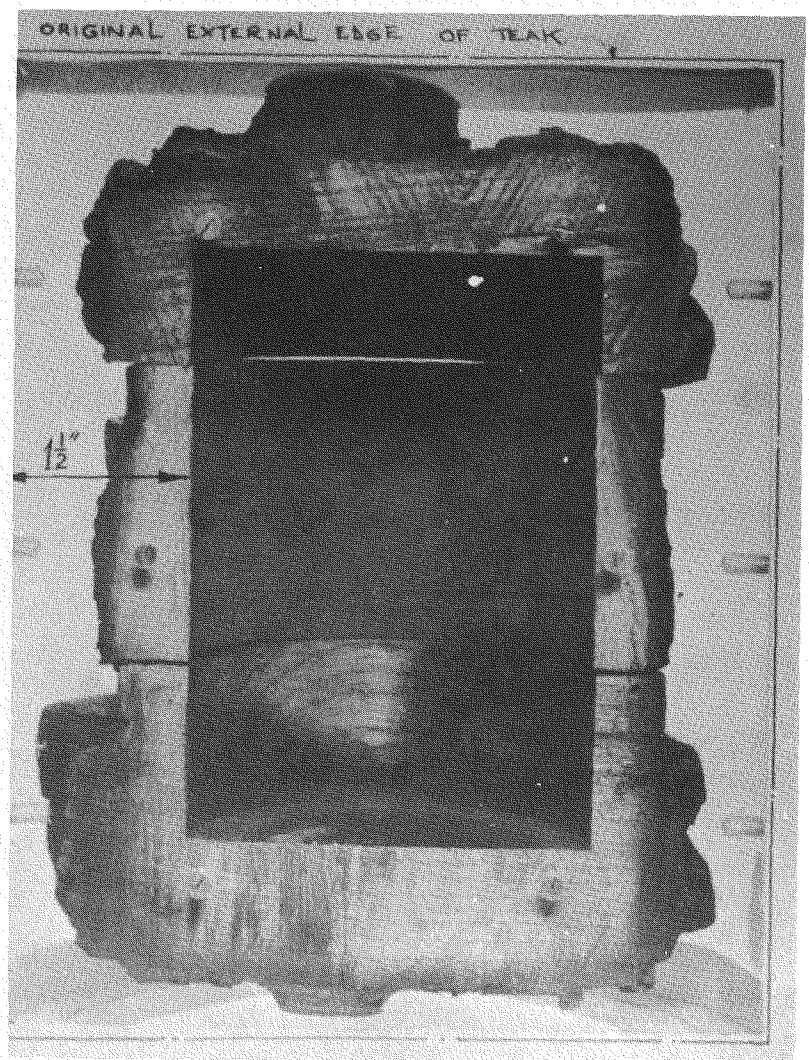


Fig. 13

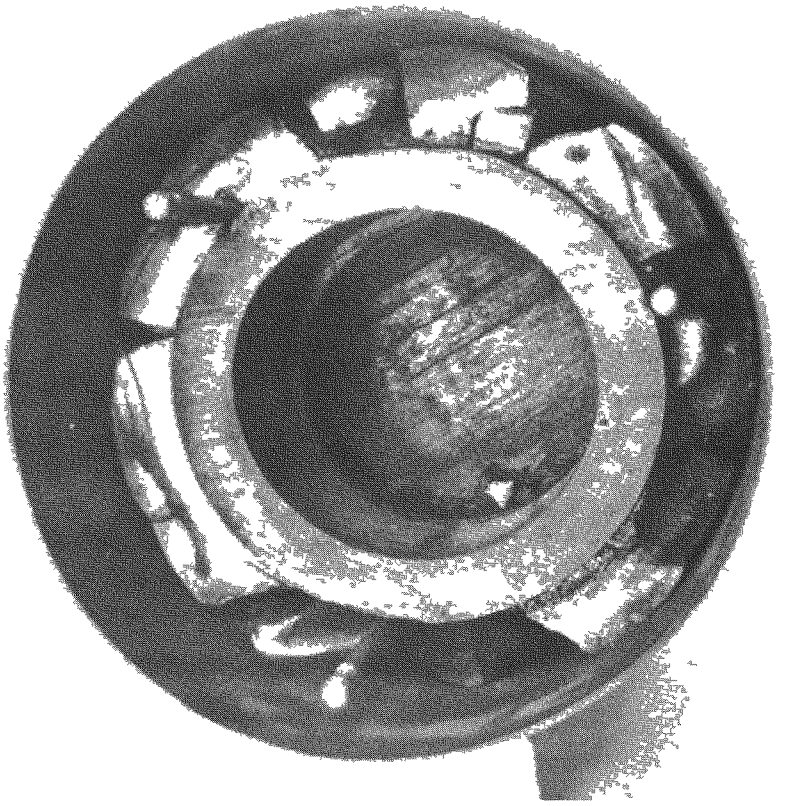


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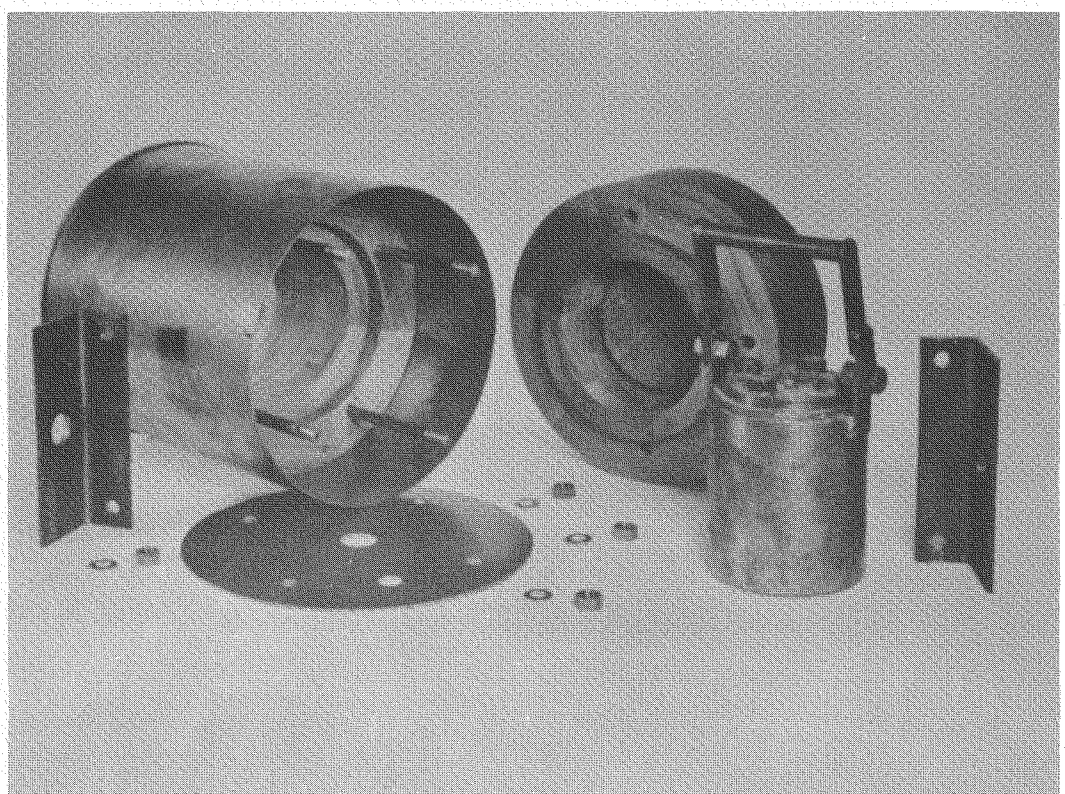


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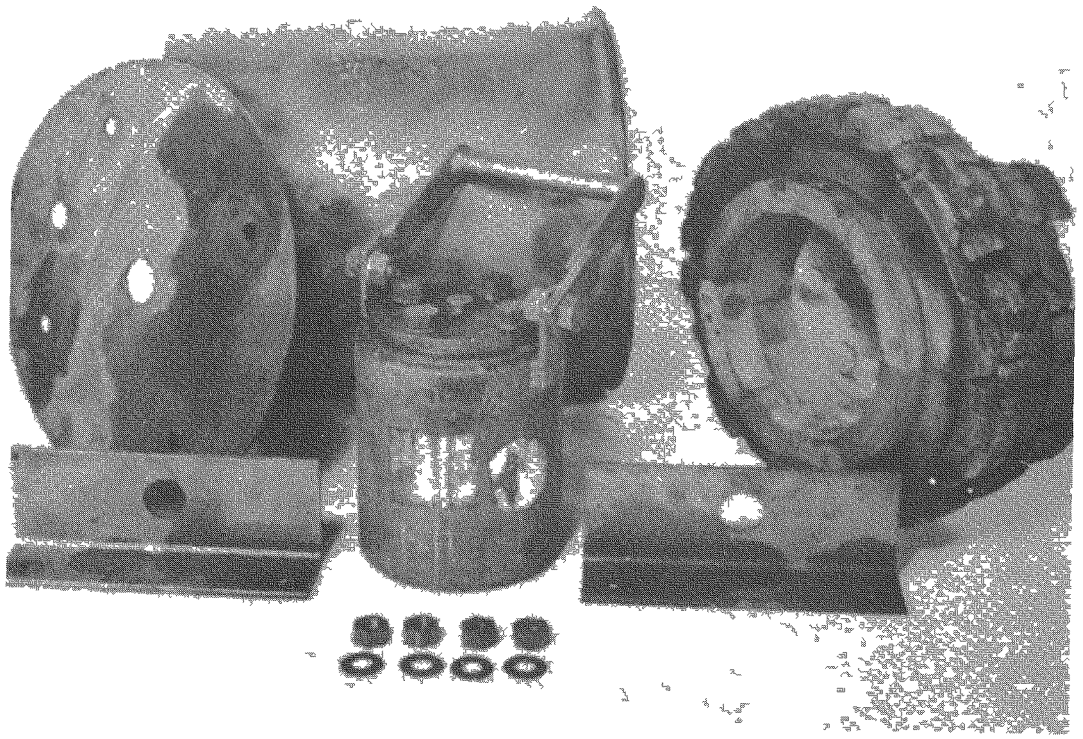


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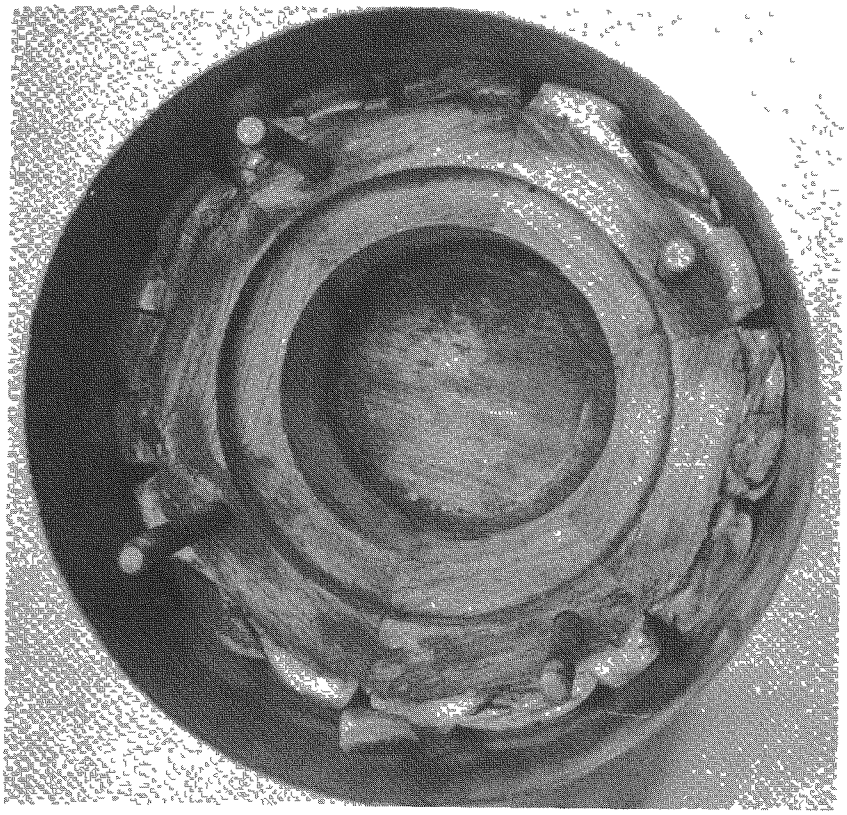


Fig. 17

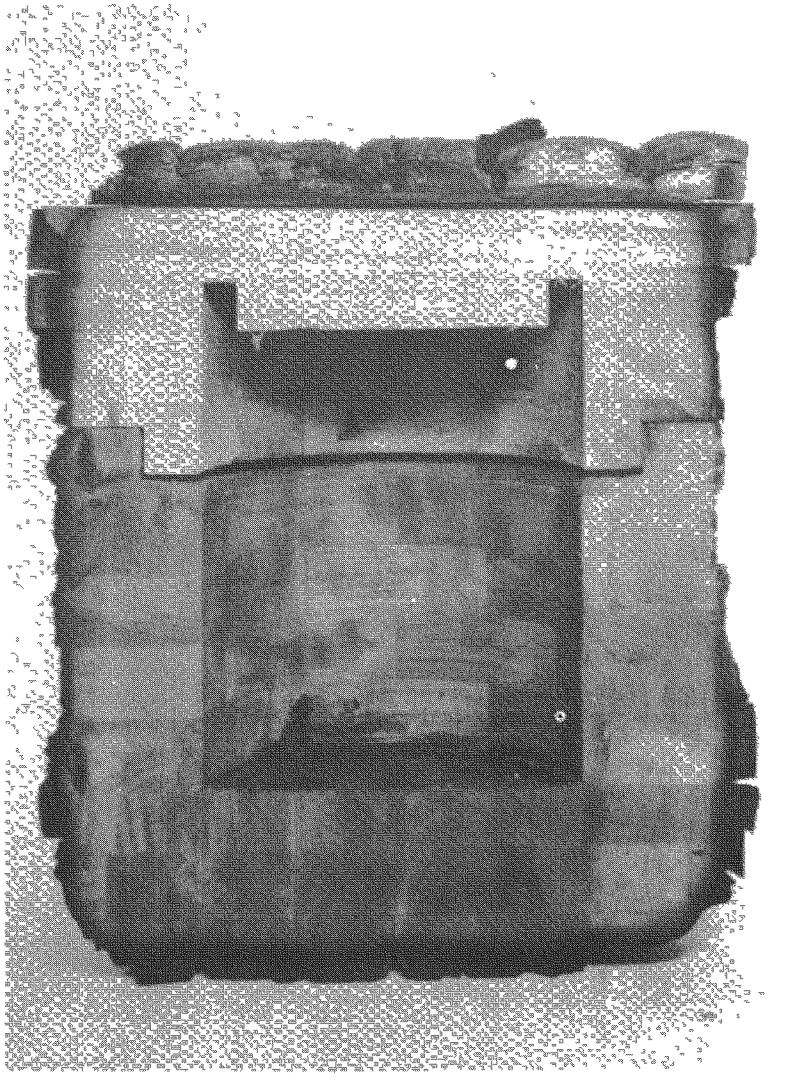


Fig. 18

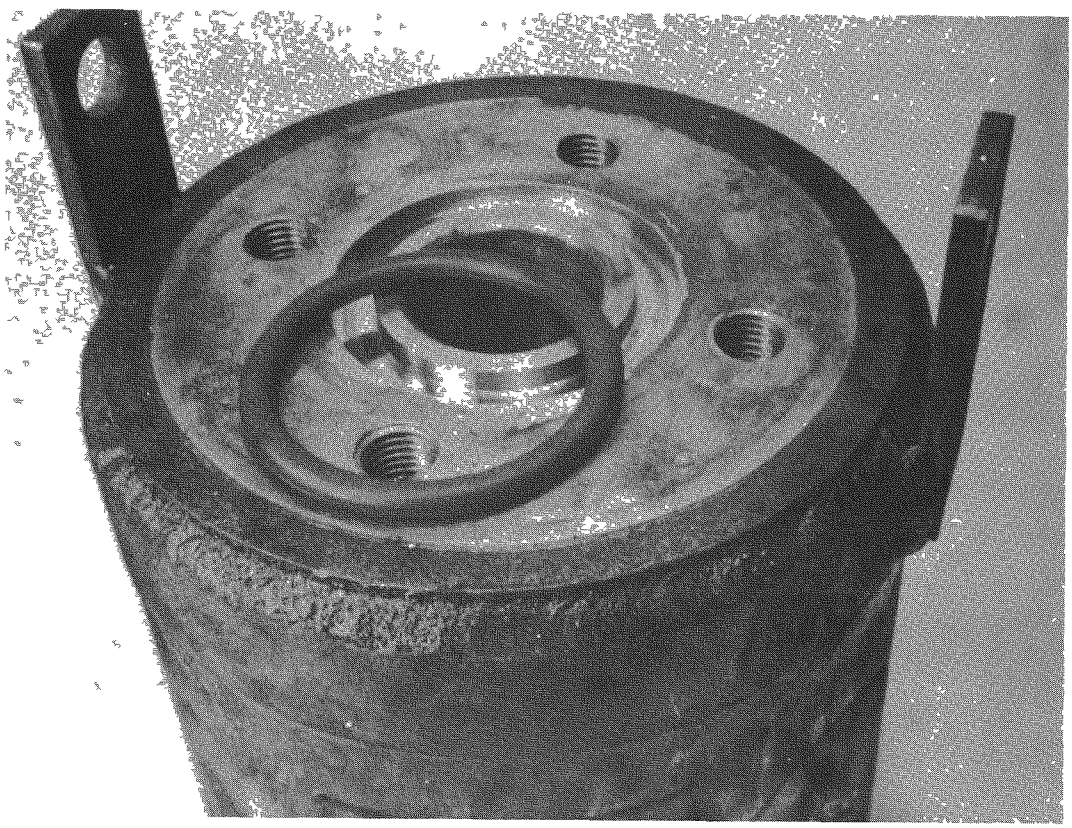


Fig. 19



Fig. 20



Fig. 21

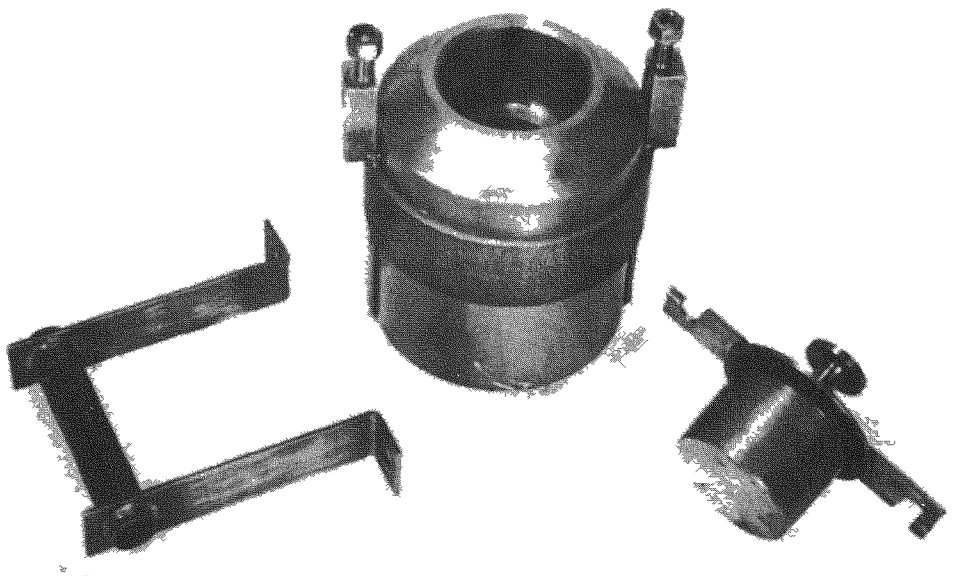


Fig. 22



Fig. 23

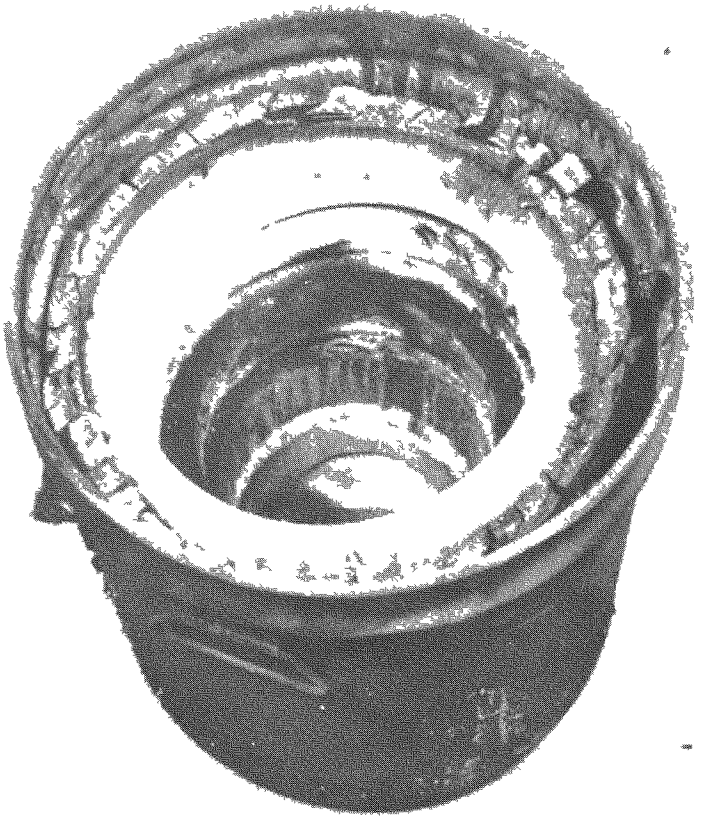


Fig. 24



Fig. 25

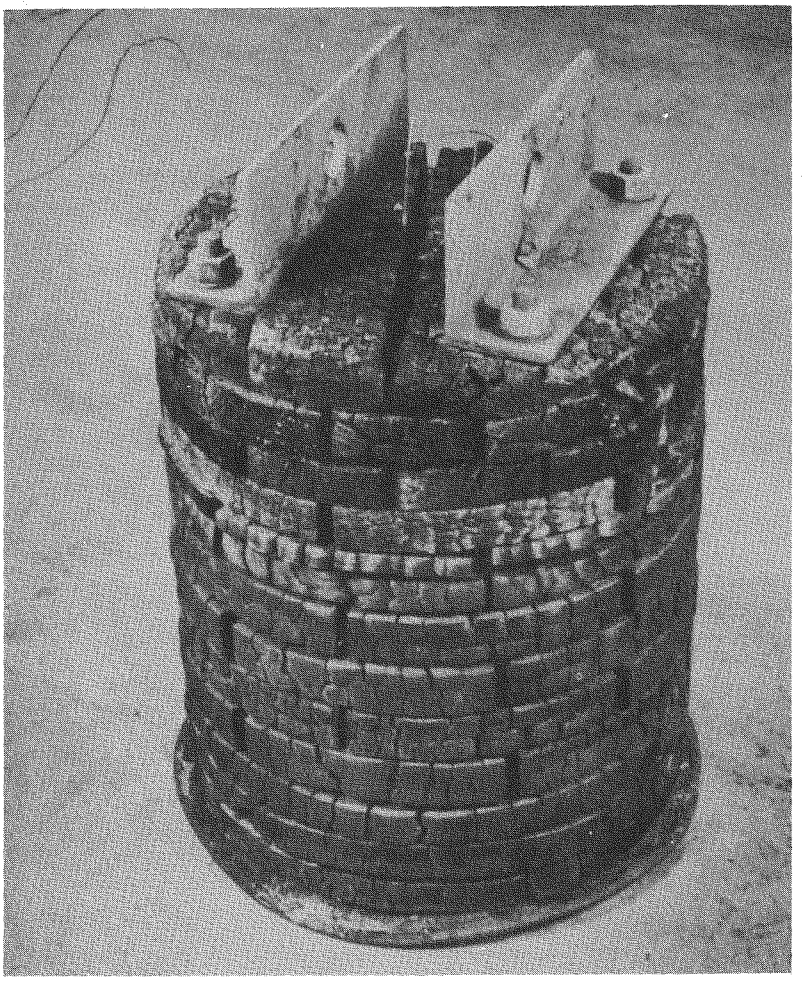


Fig. 26



Fig. 27

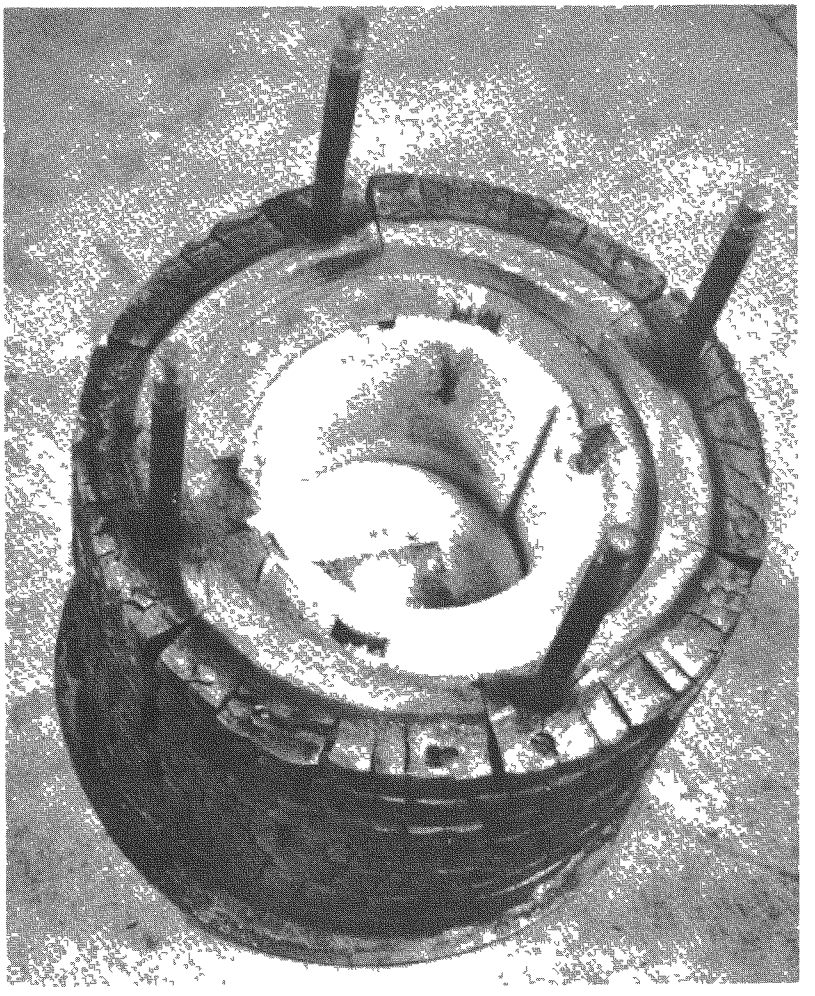


Fig. 28

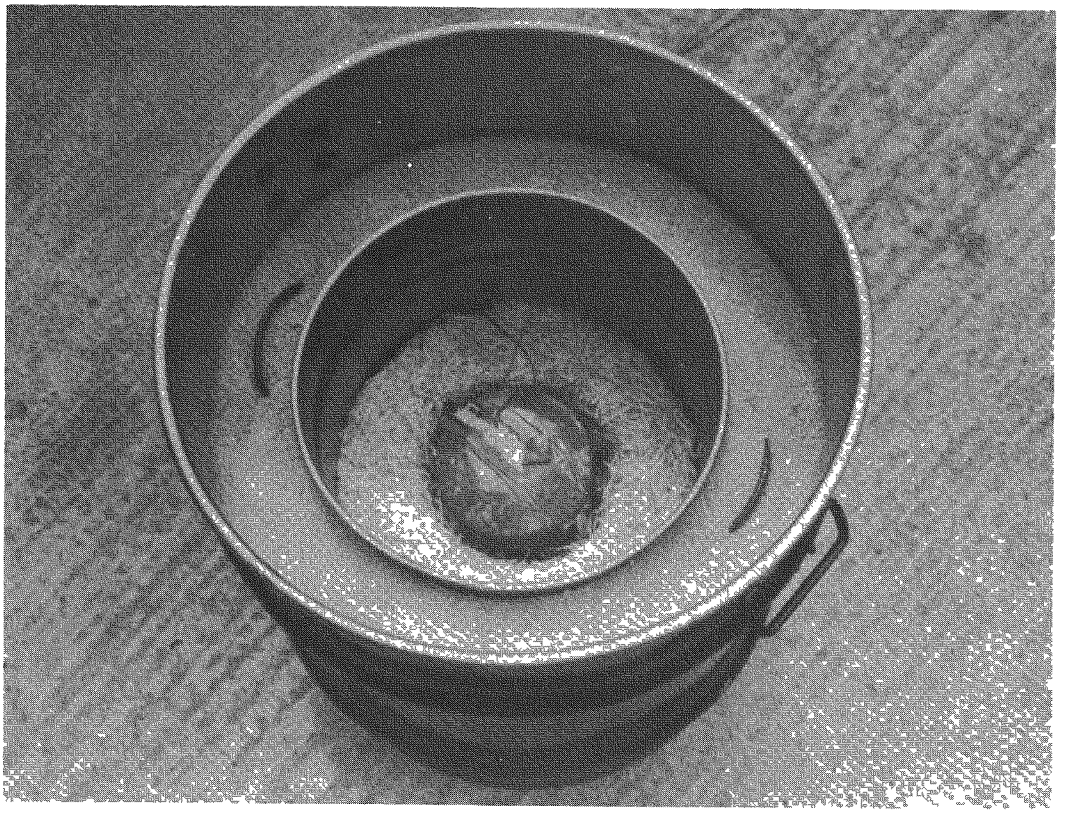


Fig. 29



Fig. 30



Fig. 31



Fig. 32

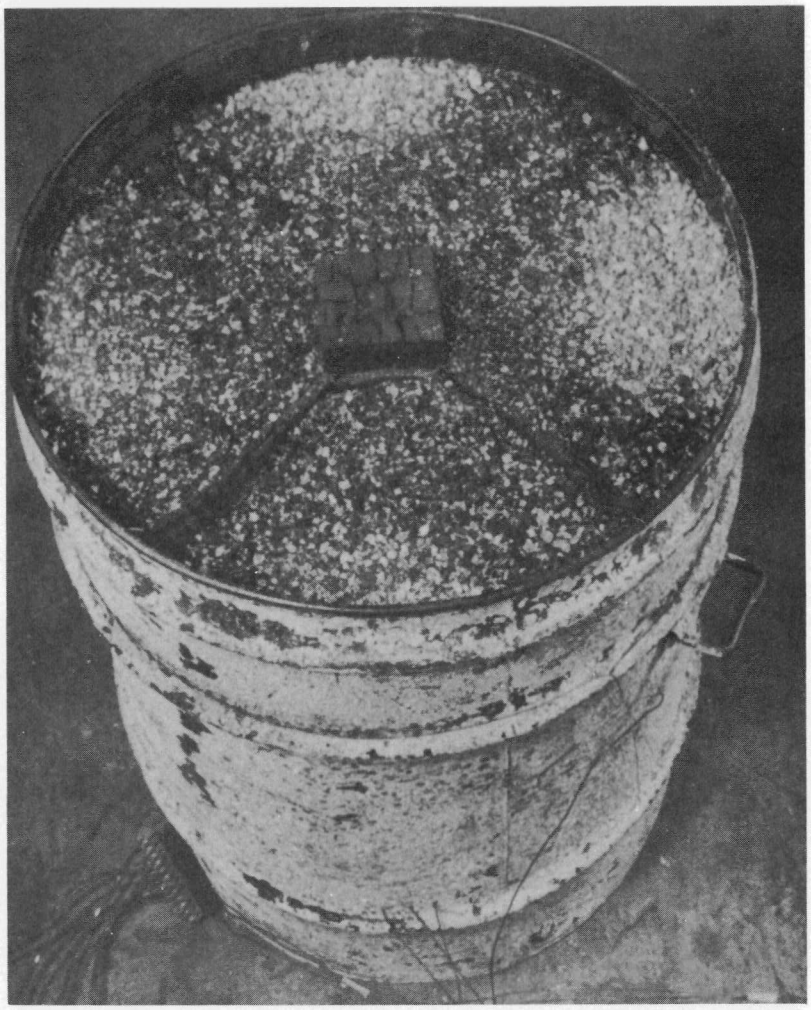


Fig. 33

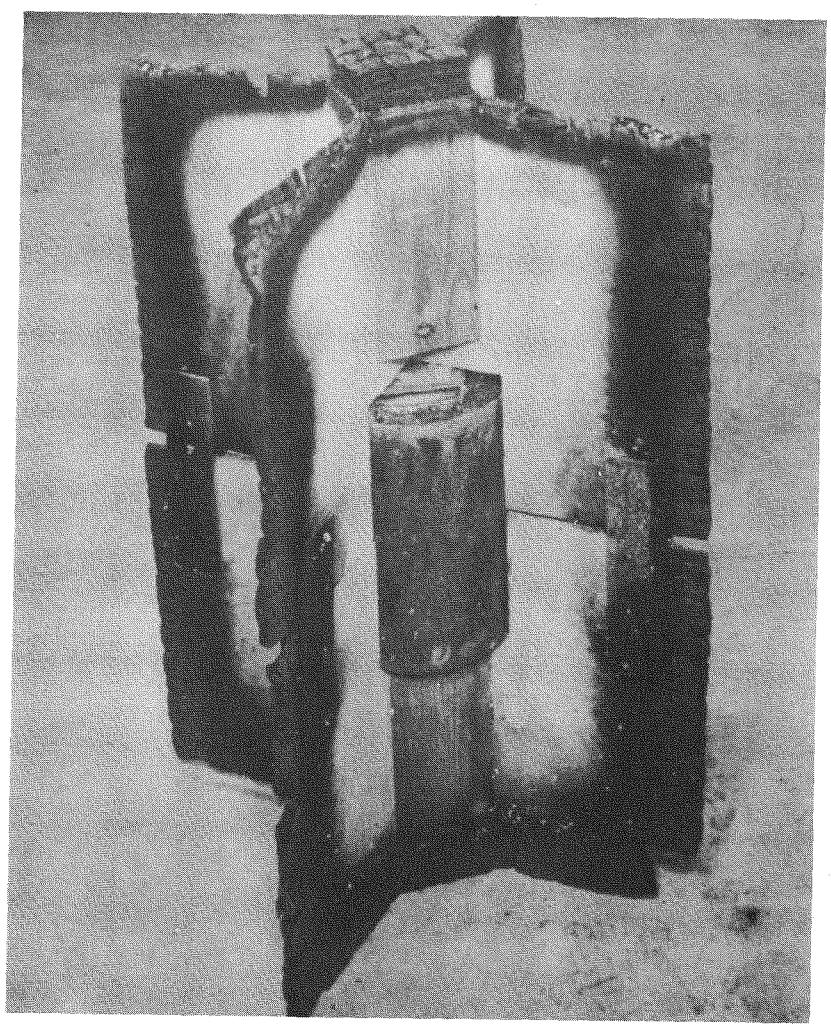


Fig. 34

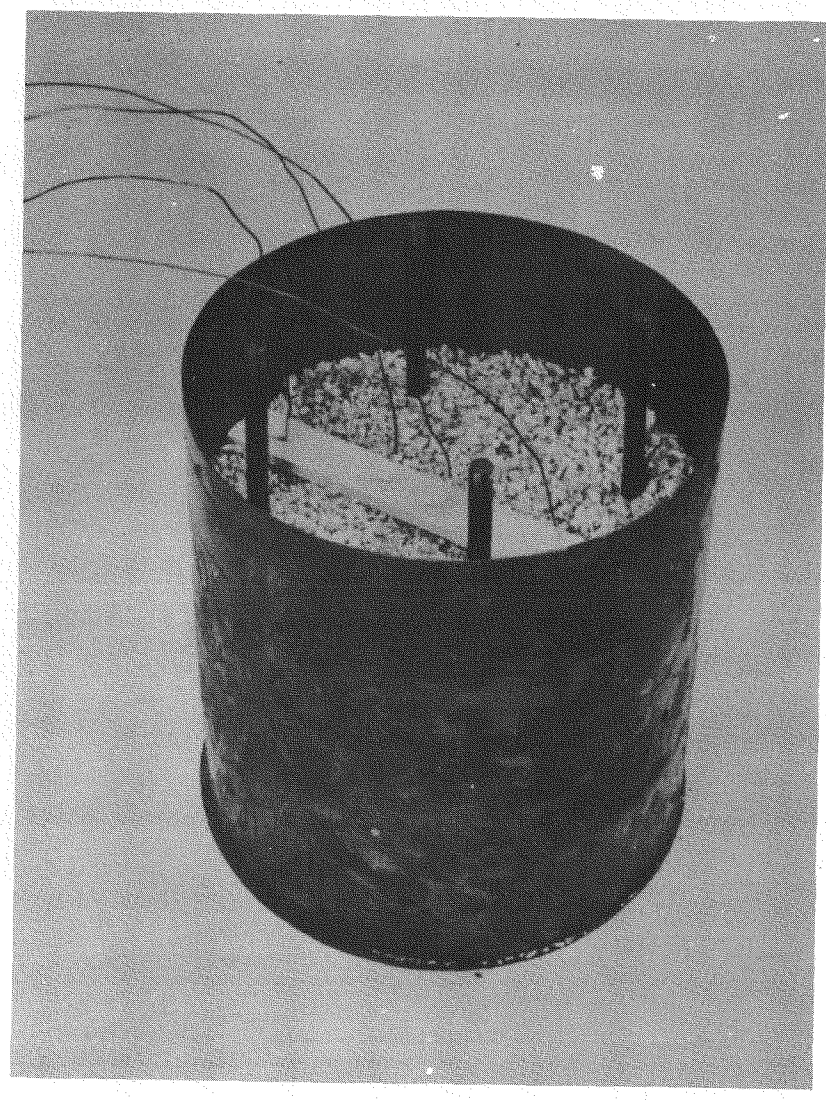


Fig. 35

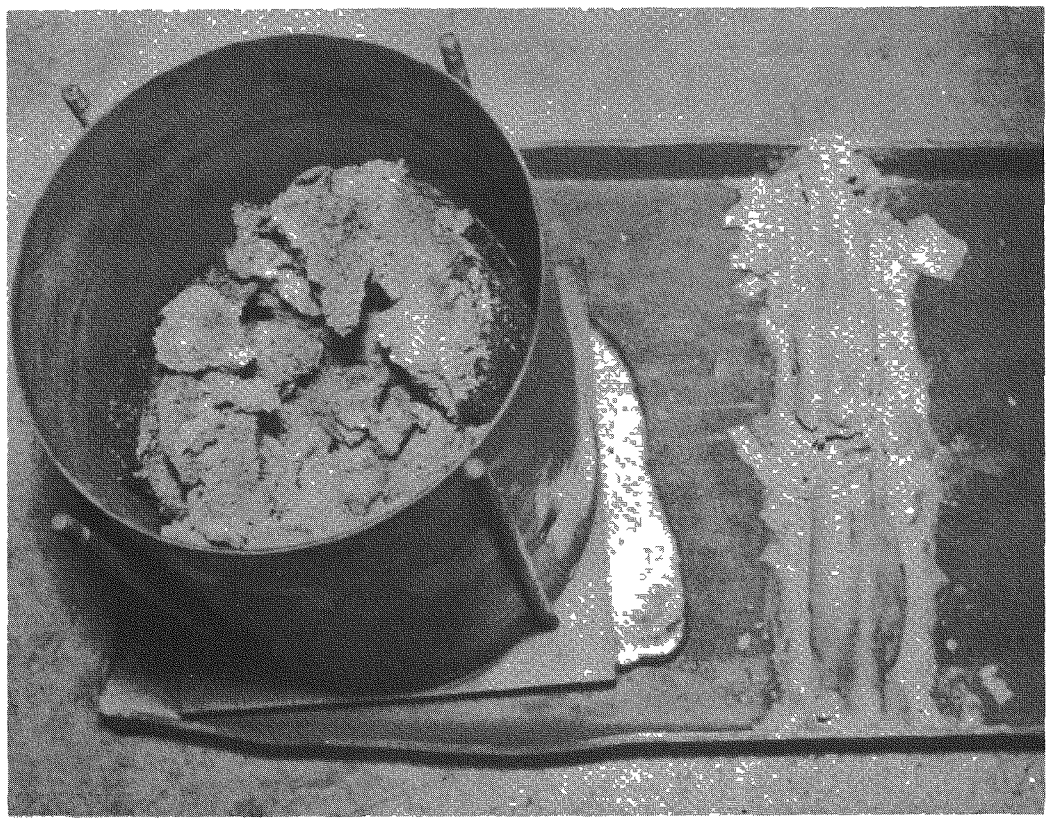


Fig. 36

FREE FALL AND FIRE TEST ON A TYPE 28 CONTAINER IN A WESTERN RED CEDAR PACKING CASE, ALL UP WEIGHT 17 Cwt.

by

F. E. Dixon

1. INTRODUCTION

1.1 Following the tests on wood insulated containers reported in paper 12 given at the symposium on the "Problems of transporting radioactive materials", the present test represents a further stage in the series in that the container used weighs 15 cwts and is the largest yet attempted in this series.

1.2 The container used was one known as the "Type 28 Flask" a lead filled mild steel container containing a stainless steel flask for carrying active liquor. Drawing No. DH 150961 registered number 0164.

1.3 The packing case was constructed in western red cedar to a Harwell design (see sketch) with battened and braced sides with steel clad corners.

1.4 The drop test was carried out at Aldermaston in September 1962 and the fire test at Harwell a few days later.

2. OBJECT OF TRIAL

2.1 To determine the mechanical and thermal protection given to the container by the packing case.

2.2 To determine the efficiency of the packing case in resisting damage and fire.

3. TEST SPECIFICATION

3.1 One drop from a height of 30' on to a 12" wide beam, the angle of the base being at 10° to the beam. The beam is that specified in AHSB(S)R.19.

4. INSTRUMENTATION

4.1 Two accelerometers were mounted on the package (this is discussed fully in the A.W.R.E. report on this drop test.)

4.2 4 Thermocouples mounted as shown on graph Z 4507 and measured with Cambridge Potentiometer.

4.3 Test Procedure

4.3.1. The assembly of packing case and container mounted on a special frame to give the 10° angle of attack

was hoisted to a height of 30' on the dropping tower, released by a standard bomb release and the accelerometer measurements taken.

4.3.2. Because the furnace loading gear would not accept the all up weight of 15 cwt the container was removed and a stainless steel tray placed on the bottom of the case. Lead billets were wired to the sides of the stainless steel tray and thermocouples attached to them. Two other thermocouples were attached to the inside walls of the case, the lid was replaced and the assembly placed in the furnace at 800°C.

5. RESULTS

5.1 Shock wave records may be seen in the A.W.R.E. report on this test. The maximum g value is in the order of 100 g.

5.2 The cross battens of the base of the case were deeply indented on the area of contact (approx. 1½"). The steel edge strip was slightly bent at the same point. The securing bolts holding the container down were driven in by the collapse of the cross battens on the base. No damage was evident on the container.

5.3 The maximum temperature rise inside the case was 59°C. Approximately ½" of solid wood was left on the inside of the case walls about 1½" being charred. Minor discolouration due to combustion products was noticed on the white felt inside the case. Brass screws securing the edge strips had melted in some cases. All the interior battening was unaffected.

6. DISCUSSION

6.1 The g levels recorded were the lowest yet achieved in this series of tests, obviously due to the deformation of the wood.

6.2 The fire test results compare with those previously obtained in tests on smaller containers, bearing in mind that Western Red Cedar is classified as only "medium fire resistance."

7. CONCLUSIONS

7.1 That wood cladding may be satisfactorily used to give both mechanical and thermal protection to a medium weight transport container.

7.2 That existing containers at present classed as B_2 may be regarded B_1 if fitted with timber transport cases.

7.3 That this wood cladding is an economic means of providing protection (cost of case 50, cost of container 500.)

Remarks by Mr. Dixon: After the very sophisticated papers you have heard this morning, you might think this is more hit-and-miss theories. We had a very limited budget to do this work with, and since I am at the research establishment where one of their functions is to sell isotopes, we would naturally want to get the most economic containers, because we are not selling containers, which is what a lot of people overlook in the design of containers because their prime object is to sell the product.

However, we have the isotope production unit and over the past 10 or 15 years have transported about a third of a million shipments of isotopes of varying sizes, which Mr. Gibson previously explained.

As an engineer, the first thing to do was to get a run-of-the-mill container and put it in first and see what happened to it.

The first container was a standard small pot which will take only two curies of iridium, and it was taken just from the normal run. We put this into the furnace. We had four, three kilowatt fires with fire bricks outside. The furnace temperature was only 370 degrees centigrade. At the end of this test we found that practically all the lead had run out. The container previously looked quite okay. You couldn't see anything wrong with it. But when examined after the test, it was noted that most of the welds had been cleaned away when dressing it up.

You cannot expect in a container design that all the containers will be perfect unless they are very well inspected. This is very difficult when you have lead shielding.

Having done that, we tested a Krypton 85 container which consists of two concentric tubes filled with lead between them. This, again, was done in a furnace. But this time we got up to 800 degrees C, and afterwards we found that the lead had gone from in between the tubes and finished up in the middle.

An interesting point in this test was that you could see that the glass ampule had melted and we did have a small amount of Krypton gas in there to see if we could find out where it leaked. But after the test, we never found it. Having gone that far, we decided that there must be something wrong with our designs, so we investigated the figures on lead. The lead we used was the type of the highest viscosity and purity. It melts not at the conventional figure of 327°C for pure lead but somewhere around 315°C. It has a viscosity very nearly equal to that of water, which shows how it can go out through the cracks. It expands 4.1 percent from solid to liquid, and the total expansion up to 800°C is calculated at 12 percent.

Because of the sudden change of volume, we did an experiment at a low temperature. We took a container which had the lead machined to fit the container to make sure there were no voids. At about 280 or 290°C, well below the melting point of lead, the container split. Our Lead Development Association said this was probably due to the fact that there were no pockets in the lead. But, nevertheless, it does prove that the high temperatures you get in a fire are not the prime cause of the loss of lead. It is the low temperatures, around 300 or 350°C when we consider the damage is done to the container.

Having gotten to this stage, we follow the same line that you have done, not because we knew what you were doing. We put a vacuum ring in the bottom. We put a vacuum ring in for the simple reason that if you leave the void filled with air, you will get air pressure and if you get a crack the air pressure will force your lead out.

The air pressure which will get up to about 60 or 70 pounds per square inch. This is one of the reasons why the lead flows freely out of a small crack.

We did two containers with compensating rings in them. In one the lead obviously did not melt all over at the same time. This is a very important point. It melted at the top first. It didn't get down far enough in pressure to collapse the vacuum ring, and the lead came out through the holes in the top of the container.

The second one, with a compensating ring, was the only container which did not burst. It did, however, distort badly. Had we dropped this one and strained the welds beforehand, there is not the slightest doubt that it would have burst.

When we sectioned this container, we found the void which was somewhere in the region of 10 percent. Because of this, we did some paper studies on containers, which are not listed here, in which we came to the conclusion that voids are not practical in containers. If the container is more than one piece, and many containers are, you will have great difficulty in determining where the voids are going to be after melting.

So we came to the conclusion that we had to provide thermal and mechanical protection for the container. Following up some information from the Timber Research Council, we chose wood for this. We put a block of teak two inches thick with lead on the inside and a steel container around the outside in a furnace. In one case we left it for a half-hour and in another case for 50 minutes and in no case did we get any great rise of temperature in the area between the wood and the lead. This gave us a great deal of confidence and we went on to test three different woods to get cheaper wood to use, including elm, iroko and teak. Elm was barely enough for the insulation, but teak worked out very satisfactorily.

We did this several times, just to make sure that we were getting firm results, and every time we got the same answer. Then we asked our isotope people to suggest the size of a container which they would like us to make in isotope transport.

They showed us first of all a normal 100-pound pot. We did not want to make a special pot just for test purposes. This pot was made in bare lead, not a steel-clad lead pot. Around this we had a half-inch of hard, white felt, around that an inch and a half of Iroko. And then a steel drum outside of this. The whole of this cost about 32 pounds Sterling, which is about $90 American.

This is interesting because it actually cost less than it would have cost to have built a steel-clad lead pot of the same order of shielding. Some people may say it is complicated, but if you take the distance you get with the wood into account as well as the shielding you can put a smaller pot in to get the same amount of radiation at the surface.

We got a temperature rise of about 60 degrees, at the space between the Iroko and the lead. This obviously presented us with a pot which would pass both the 30-foot drop tests and the fire test of 800°C for half-hour.

Having done this, we decided to put one in the furnace without the steel drum on the outside. This we did and we were surprised with the results we got because the temperature at the interface had only a rise of about 40°C. We didn't believe this. Mr. Barker was present when we did it and I think he was quite surprised.

This gave us a lead to show that we could, in fact, design a series of lead pots which would cover the range our isotope people wanted, from about 100 pounds up to 6,000 pounds in weight, which would carry up to 1200 curies of sodium 24 and vast amounts of iridium. This series will be under construction in the UK.

We have done tests on two of these, the smaller one I just described, and the larger one, which is in the supplementary support, which weighed 17 hundred weight or about 1900 pounds. In this case, we used a steel clad lead container because we do not think you can make containers of that size without it and handle them safely.

Se we use a steel clad lead container, which was divisable, and used that to support the wood which we put around it. This was a two-inch thick Western Cedar. The whole pot weighed, as I said, 1900 pounds. This was taken to the drop facility and it was dropped the 30 feet. It sustained no substantial damage, and we got very low G figures, which shows that if you have standoff rings or retarding devices on the container, such as softwood, you will get a lower G figure on the container.

Having tested this in the drop, we put the same container in our furnace. This time we could not put the container inside with the packaging case because we couldn't lift it, so we put the packing case inside with some lead billets just resting on the bottom of the case. This was tested for the half-hour fire and at about 900°C.

Our furnace has very large thermal capacity because it is a hardening furnace and not a testing furnace. It is really meant for hardening materials. At the end of this test there was about a half or three-quarters of an inch of wood left. We had a temperature rise of approximately 65 degrees at the container, so that no substantial harm would have come to the container.

Earlier we had dropped containers at Aldermaston, where we had facilities, weighing up to six tons. These were old containers which were not in use any more. We dropped a six-ton container, one weighing about 1450 pounds and one weighing a bit less. This led us to the opinion that you can drop practically any container and no great harm will come to the container. But the fire test we regard as the important point. We do not believe you can make any lead wall container without drastic expense.

This is borne out, of course, by the designs on the HAPO flask, which is really the same sort of thing. Mr. Horn said this morning that you ought to put the cask around the outside. Well, we have done this.

There have been other containers made and tested. These were fission material containers and they showed without a doubt that four inches of wood is an ample fire protection and ample mechanical stress for any weight up to 600 or 700 pounds.

We haven't gone higher than this because we don't have to go higher. We have no doubt whatever that you can build a container about midway.

In the UK we do not specify how you shall design your container. This is slightly different from the regulations I have seen and heard here today. We regard this as a not very good way of making regulations because it inhibits the design. These designs described this morning would not be allowed by your ICC regulations because they do not, in some cases, contain the lead and steel. But they are perfectly good containers and they will pass the two tests prescribed, which included going as high as 900°C from the very start, not a

rising curve. If we had been held down to steel clad lead containers, I don't think we would have come out with a solution as cheap as the one we have at the moment.

Session Chairman: Considering that we have only begun considering these testing programs seriously, for only a short time in the past two or three years, I would say we are making pretty good progress. It is true that we haven't reached our objective yet, which is a rather complete understanding of the behavior of materials under the influences of various kinds of energy, enough understanding so that we can predict the effects of operations or accidents on our physical transport systems. The papers presented at this Symposium speak for themselves of the progress made in these past few years.

Given a few more years, and a few more dollars, and more of the same kinds of talents being applied to study these problems, I hope we will be able to say that the only major problems remaining are those of the regulatory functions or the administrative functions.

WEDNESDAY AFTERNOON SESSION

DECEMBER 5, 1962

... The Round Table Discussion on Application of Testing Programs to Regulatory Standards convened at one-thirty o'clock, Professor J. Trueman Thompson, Moderator ...

PANEL

Leo White
Alexander E. Aikens, Jr.
Robert L. Junkins
F. F. Leimkuhler
John Langhaar
Leonard Horn
Harry Clarke

MODERATOR: Gentlemen, I know it is needless for me to say the purpose of this seminar, to use an academic word. We have here as speakers a distinguished group of gentlemen with great deal of experience in this field of the application of testing programs to regulatory standards. Before we start, I have been asked to permit one comment from the floor.

COMMENT: Mr. Horn's remarks and his pictures showing the separation of one part of a Spec 55 container from the balance of it were very impressive. Following his presentation, the point was made that temperatures of the magnitude referred to in the tests Mr. Horn described might not very frequently occur in normal transportation. In fact, within the last few months certain accidents have occurred in highway transportation in the United States in which rather substantial heat levels have been reached and because of the tremendous trend toward highway transportation in this country of all kinds of goods, dangerous and otherwise, this seems significant.

A few weeks ago, a tractor trailer loaded with 4200 gallons of gasoline, came to grief on a rather highly traveled road on the outskirts of Chicago. It collided during the night with a disabled vehicle on the pavement, not an altogether uncommon occurrence and, following this, collided with a bridge structure which carried Torrence Avenue over the expressway. The published reports and newspaper accounts, and the investigations of the ICC disclosed that when this gasoline vessel ruptured, the fire burned for six hours. The sustaining steel members of the overpass were so severely softened that roads had to be closed for some time.

The ICC is now in the process of investigating the reason for the failure of a pressure vessel which was loaded with more than 8,000 gallons of propane under 250 pounds pressure. This failure occurred as the vehicle entered a small town in New York State on July 25. An opening developed in the structure of the tank as it left the highway. The ensuing fire, which began at once,

destroyed a substantial number of homes, burned down a church which was a half mile away from the immediate location, and a number of other buildings were burned. So far, ten persons have died as a result of the fire.

It is important, under conditions being considered to have it said that there are at least some instances indicating clearly that in highway transportation in this country--and unfortunately, they are not very rare--very high levels of heat do occur.

MODERATOR: How do you define, in a physical way, or quantitatively, the integrity of a container?

COMMENT: During the course of the meetings here, it is apparent that numerous and different kinds of materials are being shipped. A good deal has been said about irradiated fuel elements. We have had not too much discussion of the other kinds of shipments that have been and are being made from very small quantities of fission products up to hundreds of thousands of curies. The form of the material being shipped has a very important bearing on the hazards of such a shipment.

An approach should be attempted to define integrity of a container in terms of a suitable material, a stand-in material, and how much of that material escapes from the container under the conditions of a test. In other words, if the container is one containing a solution, perhaps the pressure build-up encountered in a fire test might be the most serious problem. In other cases of dried materials, perhaps some decomposition of chemicals would occur and a corresponding build-up in pressure.

The definition of integrity of the container should be given in terms of fractions of material loss under a particular set of conditions.

COMMENT: There might be three criteria we could use to describe differentdegrees of container failure. The first of these would be an increase in the intensity and extent of external radiation. This could occur from deformation of the cask and a reduction in shielding thickness at some localized point or over an extended region.

The second situation would be openings in the outer shell, cracks of welds or punctures of these, which would increase the vulnerability of the cask in a subsequent fire with the resultant loss of lead shielding.

The third situation would be openings which go clear into the inner cavity and permit direct escape of the contents of the cask. Loss of closure, for instance, would be a very severe case of this.

COMMENT: The escape of activity or high external radiation levels might be considered to constitute failure of the cask. However, in defining failure, the allowable amount of external activity should perhaps depend on the extent of warning which would permit precautionary measures to be taken.

For example, a collision may occur without warning and an external radiation level of maybe 20 or 30 R per hour would be considered quite hazardous. With a fire, on the other hand, there is opportunity to warn the public and keep them out of the way so that external radiation levels after the fire of even 200 R per hour might hot be particularly hazardous. Such levels might complicate the recovery operations but might not constitute a hazard to the general public. In a similar way, the amount of escape of radioactive material from the cask considered to constitute failure might depend on the nature of this material; i. e., whether it is a dispersable material, or what kind of a material it is and what particular isotopes may be involved.

Since it is not possible in all cases to predict what the escaping material would be for a particular type of accident, it might be presumed that certain types of mechanical damage to the cask, per se, constitute failure. For example, the loss of the lid of the cask might be considered failure, even though it is not necessarily accompanied by loss of material from the cask.

(U. K. COMMENT): Mr. Chairman, we had this problem described as criteria of failure in the United Kingdom, and the same problem was discussed more widely when some of our people were at the International Standards Organization meeting on the packaging of radioactive isotopes which was held recently in Poland.

Our general attitude is based on the IAEA regulations which define the performance, which includes the integrity of the container, in terms of the environmental conditions it will withstand. The existing IAEA regulations are somewhat restrictive in this respect, and we have proposed a slight extension along the following lines: The type A package is not changed. In other words, it must prevent the escape of the contents and maintain the levels of external radiation within the required limits; that is, the limits laid down in the regulations, under all normal conditions of transport and minor accidents. This also applies to type B containers. But in addition, for type B containers the packaging must prevent any loss or dispersal of the primary radioactive contents under any foreseeable accident conditions but may allow the safe relief of contaminated gas or vapor; and (b) it must retain sufficient shielding to ensure that the radiation level at one meter from the package surface will not exceed one roentgen per hour.

This more or less agrees with the feature appearing in 10 CFR 72. We arrived at the same one roentgen at one meter independently. Those are the requirements. We have put in the test Specification No. 1.1, paragraph 10 criteria failure: "The sponsor shall demonstrate that after every test the safety test has been fulfilled by the sample in the manner and to the extent prescribed by the relevant transport regulations----" those are the vital words and we have underlined them --- "had the contents been the maximum for which approval was sought, even though the contents may have been damaged or the package rendered unservicable. Then we have enumerated the four safety requirements that you should retain the contents, limit the external radiation, prevent criticality and safely dissipate heat generated by the contents. Under each safety requirement we have given examples in the specification of the things that must not happen, but there are in fact many possible ways of failure, and we do not think it any good today to make out an exhaustive list of ways in which the container must fail.

COMMENT: In shipping large casks perhaps containing all the fuel from a reactor, we closely associate the cask with the prevention of criticality, and uppermost in our minds, regardless of fire or dropping the cask, is that the cask must maintain its shape to prevent the fuel from going critical.

MODERATOR: These are some of many things. Another question. Regulations often are stated in terms of physical specifications so that, as a result, there is little room for doubt whether or not a container has met those specifications. On the other hand, a container designer might wish to have performance criteria, so that he could exercise his own ingenuity in design, keeping in mind lowering costs as well as improving the design. The question is asked by inference, which is the better of these two systems, and is it possible to reconcile these two points of view?

COMMENT: The Bureau of Explosives does recognize that performance testing is necessary. In fact, the Bureau prefers a minimum construction requirement, basing the major performance of the cask on testing. We have

followed that procedure for some several years now. There is an area which requires construction specification but you also need performance tests to back up what you have said. Some specifications in the ICC regulations set up minimum construction standards together with performance tests. The Bureau of Explosives has recognized this throughout and I don't think there is any question that if a container manufacturer can come up with a good design which will perform, it will be approved.

COMMENT: Underwriters' Laboratories is probably one of the leading safety organizations in the United States and has always operated on the basis that the first thing one must do is ascertain the facts by test. After you have conducted enough tests, and after you have enough experience in any given situation, you can ultimately arrive at construction requirements. But almost always test and performance is required first before you can reach the construction requirements.

COMMENT: It appears that the answer to this question on the relative desirability of the performance specifications versus design specifications depends on how basic and how fundamental we might propose to be in these performance specifications. For example, basically what we are aiming for is that in a 1,000 mile shipment of the cask, the expected property damage shall not exceed so many dollars and the expectation of the facilities shall not exceed a certain figure. This is our basic performance requirement.

Now, how do we design to meet that? I don't believe it is feasible to publish that sort of regulation.

The next step is for somebody to decide what the cask design itself shall be in order to attain these goals on damage and personal injury. We can carry this on further and specify that the cask shall be built in a certain fashion. It is very difficult to draw any stark dividing line between performance specs and design specs.

COMMENT: We have been, for the past two years, engaged in trying to actually make cask designs in the light of the lack of not only regulations but standards. I think we spent more time and expended more effort in trying to establish the design criteria that we used than we did actually in performing design. The kind of criteria that the average design man is looking for are the ones that define the expected performance of the cask in terms of the emergency environment which it is expected to encounter, however remote the probability may be. It is the function of the regulatory and standards agencies to better define these criteria to the designer. Once these criteria are established, the designer then should have as much freedom as possible to use ingenuity in meeting the requirements. The criteria would include such things as the impact and fire resistance; that is, some quantitative definition of the standard conditions. The best definition of cask integrity is that the cask will not lose its efficacy in three areas of shielding, containment and nuclear safety while being involved in the extreme emergency condition. I say it this way rather than allowing some partial compromise of any of these three areas because it is very difficult to mitigate between degrees of failure, as far as the designer is concerned. Either it fails to some degree or it doesn't fail. We actually designed for no loss whatsoever in the efficacy of the shipping system under the conditions which we assumed. There is plenty of room for argument about what should be non-standard shipping conditions.

In order to fully evaluate this, one must consider the areas that have been discussed earlier, such as the potential damage, probability, and so on. This helps you get a handle on the proper emergency conditions. But when these are established, then I believe the designer can do a far better job of meeting the requirements of the shipping systems.

(CANADIAN COMMENT): A special problem arises in connection with radioactive material containers. With standard containers used for other dangerous commodities, such as sulphuric acid and so on, it is possible in some cases to prescribe the performance in such detail that you really don't need very much in the way of construction details or other design data. You usually assure this by requiring that a certain number of tests be carried out during production.

This would not be a practical requirement for large radioactive source containers. It is possible that you would do some damage to the containers as a result of the testing and you would have to build another one, unless, of course, you were able to build three or four containers in order to have one that could be used. Ideally, you would prescribe only performance, because that is what the regulatory people are interested in. They don't really care about the other details, but of necessity, they have to prescribe something in order to balance out the specification.

COMMENT: Some of these containers cost a considerable amount of money. One of the large shipping containers which ships an entire reactor core may cost upwards of $300,000.00. So testing a container like that is no small problem or no small cost.

COMMENT: In the Bureau of Explosives' approvals, we do not expect that large containers will be tested. However, it is necessary for the proponent to satisfy the Bureau that he has met certain minimum requirements. We look at the proposal overall, taking into consideration that there could be an accident. It is up to the designer to tell us what he has to do in order to meet the criteria.

MODERATOR: We have all listened to descriptions of the state of knowledge concerning the testing of containers, and also studies, partially theoretical in nature, concerning the consequences of spillage or accidents. We have also heard about the large number of different kinds of containers that exist and which are actually in use today. Mr. Meldrum suggested this involved at least 13,000 and could easily be doubled if you included all of them. In view of all this, do you think we ought to test them all?

I don't know if they want all 26,000 of them tested. I think when you begin to categorize these containers and put them into classes of relative importance, the question really centers on how many of them can you test, or can you test the numerous ones?

Further, if you don't test many of these containers or all of them, what would constitute acceptable proof that the container will behave as intended, in both normal operation and in an accident?

A secondary question is, if you were going to test, to what extent do model tests make an acceptable substitute?

COMMENT: Perhaps we should get more sophisticated about container testing and call in some who make a career of designing experiments. There is room now to do this. This would call for some replication, some control variations. The thing to do would be to try to estimate with a measured degree of accuracy how performance varies with common design variables. This can be done with a great deal of sophistication and it promises to save testing costs, by planning the experiment very well beforehand.

The Bureau of Explosives is quite familiar with performance testing because that is the way most ICC specifications are developed. Specifications are not added to the regulations unless we know they will perform in a certain

manner. The best answer to the problem is how has the container shipped. If it has been in existence and we haven't had any trouble with it, it must have done a good job. I suppose there will be a day when we may have some trouble, but you can't anticipate all these things.

For example, a perfect test was conducted at the University of Kansas this summer. Everything went according to schedule but I suggested it be shipped to San Francisco and back to New York filled with water. When it got back to New York, all the performance testing they did didn't amount to anything because they couldn't duplicate the conditions that happened in transportation. The container failed.

10 CFR Part 72 has performance specs for heat transfer and radiation shielding. It does not have performance specs for structural integrity. These would be extremely difficult to test especially in the case of a $300,000.00 cask, as has been stated. There does not seem to be any way of having a descriptive performance test and not have design criteria on these expensive casks. It is possible that replica testing might suffice for structural integrity, but we still need established criteria.

An accident involving a megacuric quantity of a separated, isolated fission product, perhaps in the form of a solution or as a finely divided salt, would be substantially worse than would be available for transport in the atmosphere, and would present a greater hazard to those nearby and perhaps an ingestion hazard later on in drinking water or vegetation. The relative availability, so-called for lack of another term, of the material being shipped has a very important bearing on the container performance criteria.

It appears that model tests can be used to predict full-scale cask response in the case of impact. I think that work has shown that we can use models and get very beneficial results.

It would appear that in the impact phenomenon, model testing is just what we need. However, I never have been a proponent of isolated testing. If you test these things, they ought to be tested in the environment in which they are to be used. They are part of a system of mechanics which involve the tie-down, the springs, the vehicle and so on, all the components. Until we have evaluated those things, we don't know what kind of force will come to your cask and you won't know exactly what to use in the performance specifications, necessarily.

The actual testing of large casks is going to be dependent on the results from models and it will be ever more necessary to assure the quality of the final cask design. Quality control in order to simulate the model and the major cask is going to be very necessary.

Models can show you what features of a cask are good or what features are bad. For example, you should be able to show through model tests what sort of stress pressures you should avoid in a cask, perhaps where you should not put corners or should not put welds, or if you should put ductile welds. These could be incorporated into a handbook of design practice, without having to perform actual tests on all casks to examine these particular features in the future.

While there may be some uncertainties in the relative performance of models and full-scale casks, and there may be some uncertainties in the case of fire resistance about how closely the actual cask would follow the calculations which are based on some data that we will accumulate, it seems to me that these uncertainties are very small compared with the uncertainties in

the type of environment to which the cask will actually be subjected. Therefore, the procedure of model testing and of calculation is entirely satisfactory for our purposes.

In quizzing fire protection engineers at Underwriters' Laboratories about model testing, I find that in some 50 years or so of running fire tests on all kinds of things they advise strongly against it. It is very difficult to scale a model down to some size that can be handled in a fire test and then try to extrapolate the results. The folks from Great Britain made the statement that they did not wish to go below 25 per cent. I think that would be a pretty good figure. Even a 25 per cent model would not make me be sure that you could predict the results of a full-scale test on that basis.

MODERATOR: I was not aware that anyone on the panel felt that model testing in the area of fire testing or thermal phenomenon was intended.

COMMENT: I endorse the suggestion of a handbook of design practices. Perhaps this handbook could serve in lieu of detailed regulations containing design requirements or performance criteria or test requirements.

MODERATOR: It has been stated that if one wanted to spend many dollars and manhours, a transportation system could be developed that would approach the ultimate in safety. However, this may be impractical and, therefore, a decision would have to be made to accept some risks in order to lower the costs. What, in your judgment, should be a guide in establishing the acceptable risks, and what are these risks? We talk about the possibility of having a heck of an accident, but you never can say you will never have such an accident. It reminds me of the Gilbert and Sullivan opera, "I am never, never sick at sea." "What, never?" "Well, hardly ever." We are concerned here with distribution of risks, the distribution of frequencies, the distribution of costs. We have at one end of the spectrum perhaps the feeling that we are willing to disregard certain things right away. At the other end, we have the rising costs and rising severity. The cut-off point is important. Ultimately, the policy decisions as to the cut-off will have to be made by management, but management can't do it in the absence of information that people like us here should be able to supply.

COMMENT: There is an aspect of this problem that hasn't really come out in this meeting or at least, it hasn't been discussed, which is latent in the whole problem. We are really struggling with "how safe is safe." The ultimate answer to that is not in our minds here or in the mind of any designer, I don't think. And I don't think, management can make this decision in the absence of accidents that actually happen. Most accidents are tempered in one way or another, when they happen, by a court decision. The ultimate answer as to what is safe, usually rests in a court where the criterion is what is reasonable. Was the man who made the shipment a reasonable man? Did he do what he reasonably could do under the circumstances?

In recent years, and particularly in the atomic energy business, there has been, in the minds of the people who are trying to make things safe, the idea that we accept absolute liability and it is probably true that this doctrine would be applied in the case of a reactor or in the case of a bad transportation accident. So I think the ultimate answer to questions such as what are the criteria to use? What are the designs of the cask, how much can you release, ultimately ends up with, "what is the public willing to accept?"

Behind this question is where do we get the insurance for the kind of accident that has occurred.

The nature of the material, and how much can get out, is definitely related to how much hazard would there be to the public. The insurance you can buy will be determined by experience only.

However, because we do not have the experience, it would be wise, I think, in trying to arrive at the ultimate criteria on which to base procedures and designs, to rely upon what a reasonable man could expect or what a reasonable man would design for.

There are steps in this direction already. For instance, there has been a decision made within the Commission in respect to the shipment of plutonium in weapons shipments. Criteria have been set. We think of what could be the worst thing that could happen to the public and we have characterized that with a number. It must be kept in mind that the ultimate answer to what risk is involved is going to rest in a court, and they, in turn, will say what did a reasonable man do when he designed this cask.

So I think there ought to be more thought given to the possible consequences to the public, the loss of use of property, and injury to people, when we are trying to arrive at the criteria which ultimately ends up in a physical piece of equipment.

MODERATOR: In many instances the decision has to be made as to how much risk we are willing to accept. Somebody has to make it. It may be that some brave test designers will make it.

COMMENT: As far as the idea of inflicting the risk on the public, this has been done in the field of quality control; i. e., the risk of delivering poor products to the customer. There you will find a rather arbitrary risk level set, although people do attempt to arrive at a reasonable level of risk, based on an economic criteria. It would be difficult to fully answer the question until we know exactly what accidents can cost. We are a long way from finding this out. We had estimates of how design variables, common design variables, will affect performance. We had another relationship as to the costs for these common design variables. This is a great deal of information on which to base decisions. For example, if it cost a couple of thousand dollars to add a light to a runway and this light would help the landing of aircraft, there isn't much question of whether you will add that light to the runway. Of course, there will be a limit as to how many lights you will add to a runway. But, if it does not cost much to add additional safety, build safety into a container. We should build into the container as much safety as is reasonable, cost-wise.

It is only recently that cost information is coming out. There is a great need for more cost information relative to design. If as much of this information could be forthcoming as performance relative to design, I think we would be a lot further along the way.

We have to realize that every day in our life we are living with risk. It doesn't matter what you talk about. We have to accept that there is a risk in transporting certain materials. If we hadn't accepted that philosophy, we would never have moved a pound of dynamite in this country. A reasonable risk for the shipment of radioactive materials might be expressed this way: that the expected dollar damage from radiation should be of the same order of magnitude as the damage experienced with other dangerous cargo per vehicle mile , unless and until operations and research studies would show that some smaller risk would be economically desirable. In connection with dollar damage, I am assuming that we can place a dollar value on human injury and on death. There is an added factor in the whole problem which we are all aware of. The public

has not yet come to accept risk in the radiation field as they do in other cases. In the regular everyday operation of the safety program, five men may be killed in a construction accident and they merely become statistics. But let an individual get 5 rem or 1-1/2 rem above what he is supposed to get and it requires special reports with detailed explanations.

The public isn't ready to accept these risks yet, and, therefore, we have to be more careful. There is an element of risk in this atomic energy business which doesn't exist in any other field, and that is the risk not only to ourselves in this generation, but also the risk to future generations. Perhaps that is why the risk has not yet been accepted.

In the radiation field, there has been a lot of emphasis placed on the genetic effects. This is also true of many of the chemical industries. We have built into our tolerance these genetic effects, where they don't in the chemical industry. I don't think the radiation hazards, to a degree, are any different than in many other industries for this generation or the next.

MODERATOR: The next question says that in testing containers it has been determined that they can be penetrated relatively easily by low air drops. What does this mean in terms of actual hazards and their evaluation?

COMMENT: It is my impression that we don't have sufficient numbers available to us to answer this question. There are many conflicting opinions about the hazard, its occurrence, whether it is possible, how often it occurs, and I have not been able to find any statistics which would indicate to me whether this is a real hazard or not.

The hazard, if it is one, is that perhaps if the steel cladding of a container is punctured, and then the container gets mixed up in the fire, perhaps this is the hole through which the lead shielding would come out.

On the other hand, in many systems of hazard evaluation, the criterion is one hazard at a time, and not the simultaneous piling up of one incident on top of another. Perhaps some thought could be given to this kind of a philosophy in the statement of this principle.

If we assume it is possible to penetrate the inner container, the extent of the hazard is greatly dependent upon the exact nature of the contents and, secondly, the environment in which it is placed. If the contents are fuel elements, there is good reason to believe that the fuel elements would remain intact with their cladding around them and I would visualize that you might lose a small amount of coolant with a small amount of contamination. But I do not visualize that that would be a catastrophic accident. Additionally, of course, there would be a bit of radiation that could be troublesome. But it would not affect large numbers of people.

However, if the contents were some material that was soluble in water, and this accident occurred on a bridge, or such location, where it contaminated a surface water supply, it could be very serious. There is a spectrum of things in between those two points in terms of the seriousness of the penetration of this sort. I think primarily it would be dependent upon the exact physical and chemical nature of the contents and, additionally then, dependent upon the particular environment where it occurred.

At the present time, the regulations are concerned also about penetration of the outer shall, even though the inner shell may not fail. The hazard involved in penetration of the outer shell appears small since it is very unlikely that such a penetration accident would be followed by a fire. Also, if a fire should develop, the public will certainly be cleared out of the way

and will be kept out of the way so that subsequent high radiation levels would not constitute a serious hazard.

On this matter of a fire, if you have a material that is quite volatile or perhaps finely divided powders it may be necessary to evacuate a rather large area, depending upon the particular atmospheric conditions which prevailed at the time.

MODERATOR: Question 8 talks about a credible accident. This is related to the 9th question which concerns the set of specifications proposed in the definition for a credible accident, requiring among other things, resistance to impact, puncture and fire. While not so stated, the specifications require resistance to fire following impact or puncture. Is this a reasonable requirement? Is it credible to assume that you will have a puncture and then a fire in a chain of events?

COMMENT: Cask approvals are currently analyzed on the basis of a single accident condition. It seems more incredible that you would have a fire that was not preceded by accident than it is that you will have a fire that has been preceded by an accident. The conditions of accident are the main contributors to a fire in the case of a shipping accident. So in designing the fission product cask, we have felt that the credible accident is the impact followed by the fire.

The criterion for the puncture test is that the outer shell does not exceed the ultimate strength of the material and the criterion for the impact test is the same thing, that the outer shell does not exceed the ultimate strength. The only reason for stating the failure conditions in these terms is that one must assume that if the outer shell fails, a fire will then cause the shielding material to escape from the container.

MODERATOR: The IAEA regulations specify that a type B container be capable of surviving a credible accident. That is a statement of fact. Is it your opinion that this should be the worst accident conceivable or should the credible accident be based on some probability?

COMMENT: There is a whole spectrum of accidents that have taken place and which have been observed from an accident which results in no release of any radioactive material and no loss of shielding, to the other end of the scale where some very severe accident could be designated as the worst one.

It has been necessary in the past for people to define a set of design conditions within this spectrum, and there has been a tendency to call this level the maximum credible accident. To me, the accident that is incredible is just the one that hasn't happened yet, but which may happen tomorrow. It is quite reasonable to draw a line and say this is the level to which I can protect the shipment by virtue of design considerations.

But it is also just as reasonable to look at the whole transportation system and do some other things outside of just the design of the vessel and perhaps the container around it, that are reasonable, and perhaps do a couple of unreasonable ones, in the light of the public concern over this kind of possibility.

You have an arbitrary accident condition that is really just one point on the curve. If we had knowledge of the curve of severity of an accident measured in some terms, versus the probability of its occurrence, the magnitude of probability would be one point on that curve. I don't think it needs anything special in the way of treatment other than as the result of reasonable men's thinking about what conditions can we design for.

(U. K. COMMENT): The IAEA definition of a maximum credible accident says it is a possible accident or series of accidents, the occurrence of which, although unlikely, must be taken into account in relation to all arrangements in connection with that mode of transport.

Although we mostly wear hats with, "I like IAEA," on them, this is perhaps a rope around our own neck. When this was first seen by our own transport authorities, they postulated the 30 mile an hour train meeting a truck on a level crossing and knocking it first into a bridge abutment and then down an embankment into a reservoir. We could only answer that we thought it reasonable to add an aircraft crashing into the reservoir at the same time. We are hopeful that in the revision of IAEA that the maximum credible will become the maximum foreseeable accident because we think there is almost no limit to the credibility of human beings, but there is a limit to their farsightedness, and we could define this in terms of test specifications.

In other words, the maximum credible accident would represent the conditions of certain agreed tests for the different standards of packaging and the tests would not be obligatory. You could either subject your container design to that test or you could provide the calculations or experience to prove that a test was unnecessary. It is this translation of the maximum credible accident into test which puts into real terms the test specifications which we are looking for at this moment.

COMMENT: I think we are trying to buy entirely too much insurance on these accidents and it may wind up bankrupting the atomic energy industry. I think it might be wise if we would consult a few insurance underwriters and find out just how much risk it is practical to try to consider in a situation like this and not try to design for every conceivable accident that our minds might devise.

MODERATOR: Has anyone considered the possibility of using materials of construction other than lead and steel? If so, what are the advantages and disadvantages? If economics had ruled out certain types of materials, has such a design been evaluated with respect to the so-called accident risk cost suggested in Dr. Leimkuhler's paper?

COMMENT: Uranium has been given consideration as a shielding material. Others than myself have made more specific evaluation of the merits of using uranium. At the time I made a preliminary examination it appeared to be not only costly, but it would result in a lighter cask. At that time, the technology of processing uranium for this purpose was not sufficiently developed. Further studies of this have been made at Oak Ridge. A very excellent cobalt 60 teletherapy machine is in operation at the Argonne Cancer Laboratory in Chicago which uses uranium for shielding. I believe it was designed at Oak Ridge so this can be done for certain applications.

There is considerable experience in this area in shields for the SNAP radioisotope generators which, in turn, serve as shipping casks. They are fabricated with shielding bonded to Hasteloy-C cladding. This is a pretty expensive operation to go through, both from materials cost and fabrication cost. It is justified only because of the ultimate environment these generators experience. It is certainly not the controlled environment that is perhaps fairly standard in shipping something within this country for one must take into account such things as accidental immersion in sea water for hundreds of years.

We employ a low melting lead alloy as a bond between the depleted uranium and the Hasteloy-C, both of which have been pre-tinned and find that we get

excellent heat transfer which is absolutely necessary for our systems in operation. They are heat generating systems with the heat being provided internally through the decay of the radioisotopes.

These systems have not been tested physically but they have been analyzed for purposes of licensing. There have been no drop tests or fire tests conducted on these specific land-based systems which employ strontium 90 as the radioisotope. The larger of these systems weighs about 4,000 pounds and contains 225,000 curies of strontium 90, the shielding efficiency being such that the ICC regulation is met for shipping without escort. Our actual radiation levels run to the order of 30 to 50 mr per hour at the surface.

In the land-base programs we have employed actual fire tests on devices which are exact duplicates of fuel generators but which do not contain the radioisotopes. In these tests, we subject generators to fires resulting from ignition of fuels of the type used in missile boosters. Typical flame temperatures in fires such as these run to 4,000 degrees Fahrenheit for short times and perhaps higher which makes a problem of pyrometry. Our experience has been that the devices themselves are not subject to anywhere near this temperature. These tests are actual fires, of the same fuels employed in the missiles.

We have subjected generators whose outer shells are made of magnesium to such fires and have had the magnesium partially melt but not even catch fire. Although this can only be qualitative in the sense of applying it to other situations, it is indicative of the fact that I am not a believer at all in doing fire tests by placing objects in a furnace and holding them in a steady state for long periods of time.

There are containers in use today for shipment of various isotopes that have uranium shielding. For that reason, ICC Specification 55 was amended about three years ago to permit the use of uranium as a shielding material. There are other teletherapy units in this country that employ tungsten. So there are other materials that are used.

Of course, we have been talking of gamma radiation. For neutrons, there are several materials that are being used.

We haven't touched much on cost, but I did get the general impression that the cost would be high. It is a question of balancing cost against the gains, or against the excessive risks, I suppose.

(UK COMMENT)

In a study of transport costs uranium containers balance out at around three to four years when the capital cost is compared to the transport cost; that is, the costs are comparable to a cheaper lead pot which weighs more and has greater transport charges at that time. This is a critical point to remember. On other shielding materials, we have used wood. You have a great deal of space from wood and, when you use heavier metals, like uranium, you lose space so you haven't a direct comparison between the uranium cost and the lead costs. That is, it requires more shielding material because there is less distance. We have also tried some plastics and materials of that kind, but they were not satisfactory. Concrete is used extensively for shielding low amounts of radioactivity and wastes, in particular.

On small items, such as radiography equipment, using uranium shielding, we find that the cost runs about twice what the cost is for lead. Naturally, you can use uranium with much better shielding qualities and decrease your size and the weight, but it just about runs to twice the cost.

People have expressed the view that where they have justified expensive containers, they are using them. Admittedly, this is a subjective judgment on their part, but it comes in in a qualitative way and not yet a quantitative way.

MODERATOR: Do you feel that a protective container can be designed at a reasonable cost for all means of transportation or is there enough difference that a container should be restricted for use by air, rail, or motor vehicle as specified?

COMMENT: There are containers that will function better in one service than another, and certainly when there are requests for air transportation, as advisors to the FAA, we have put certain limitations on containers that move by air.

The shipping criteria for accidents should be based on an assessment of the environmental conditions that may be encountered under accident conditions. I feel that the probability of encountering a particular environment in an accident is different in air, rail, and motor vehicle transport and, therefore, the criteria for protective containers should be different in each case.

An air shipment, ultimately has to be shipped by truck. So, really, the question ought to be turned around: How important is it to design containers to meet all three?

I think probably in the case of many small containers it is important that a standard set of criteria or standard requirements be made for all three, since the shipments are likely to see all three modes of transportation. One should add ship transport, incidentally.

This is absolutely true on small containers. For instance, there are probably several hundred shipments every month by air. Those same packages are acceptable by any means of transportation, whether it be land or water.

MODERATOR: The case was suggested of a cask containing some high curie content, or a substance of great activity, arriving from a producer of strontium, at a plant in another part of the country, which may be quite distant. This cask is then emptied and the material put to use in some manufacturing process.

Then they discover that the cask still has a residual amount of activity left in it. If they just shut up the cask and ship it back, and it was escorted coming, must it be escorted going back? If they are going to empty and clean the cask for shipment back to the plant, who bears the expense of doing all this? Two very practical questions.

COMMENT: If the container moves in under courier service, it can be moved back contaminated on the inside, provided it moves as a radioactive shipment and it does not require a courier on the return.

A cask of the type described by Mr. Smith, of Hanford, was shipped from Hanford to central Pennsylvania under escort. It was unloaded. It contained originally 96,000 curies of strontium 90. It was decontaminated and preparations made to return it containing some indeterminate amount of strontium 90. The definition of an empty cask that has been employed for freight tariff purposes is that it contains

less than about 3 millicuries; that there be no significant contamination on the outside and that the radiation level at contact be less than 10 mr in 24 hours.

We emptied this cask leaving a few hundred curies inside. There was no way of measuring the actual amount inside. Furthermore, there was contamination on this cask because it had been in service in several shipments, and this contamination, I assume, was significant because it was something like 200 dpm per 200 square centimeters. To us, it is significant that it can be measured, but it does not constitute a health hazard, since casks containing contamination like this move regularly in Interstate Commerce.

Several days were spent in resolving this and it finally resulted in a change in the Bureau of Explosives permit for the return of the cask.

(IAEA COMMENT): The meeting has been extremely interesting to us, and the great amount of thinking and experimental work which has been carried forward in the field of containers lately will help us a great deal to improve our regulations when they are revised next year. We hope that when the IAEA regulations have been revised, they will provide a lasting and practical framework for international harmonization of transport regulations.

In that connection, I think we will proceed with the performance regulations as the first step, but we certainly hope to improve these regulations also by giving design specifications in due course, and in that respect, I am sure that the work which is done in the most advanced countries could be introduced into our regulations, for instance, as examples, which would be of great help to the less advanced countries.

I know meetings of this kind are very profitable to the work of the Agency.

The following questions were referred to the Panel but were not discussed:

In view of the increasing number of different kinds of containers, what are the possibilities for standardization of containers, from a technical standpoint?

One approach used to achieve safety in transporting radioactive materials is to surround the container itself with an energy absorption means or a crash shield. Do you believe this kind of approach can supplant design of integrity into containers? If not, to what degree can they be relied on to replace weaknesses in containers?

From the experiences gained in testing, do you feel it would be possible to design containers to meet simple performance specifications rather than detailed standards?

In designing containers to resist failure, what factors do you consider most important?

Of the performance specifications proposed, what do you think is the most difficult to design for?

Is the UK idea of testing by maximum impact followed by maximum fire desirable and how does this relate to the extent of risk?

Is there a present need in the field, and is the state of the art sufficiently advanced, to recommend writing a comprehensive technical book on the subject of "Transportation of Radioactive Materials"? If yes, what should be the specific purposes in the writing?

Should consideration be given in casks for the presence of spontaneous fission in the higher transuranic elements to be formed in the higher MWD fuel elements in the power reactors of the future? You may have a good gamma container but be limited by the neutrons being emitted.

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