AIIM

Association for Information and Image Management

1100 Wayne Avenue, Suite 1100
Silver Spring, Maryland 20910
301/587-8202

Centimeter

Inches

MANUFACTURED TO AIIM STANDARDS
BY APPLIED IMAGE, INC.

46-77358

**Cover Sheet for a Hanford
Historical Document
Released for Public Availability**

Released 1994

**Prepared for the U.S. Department of Energy
under Contract DE-AC06-76RLO 1830**

**Pacific Northwest Laboratory
Operated for the U.S. Department of Energy
by Battelle Memorial Institute**

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

**RECEIVED
MAY 14 1994
JSTI**

DISCLAIMER

This is a **historical document** that is being released for public availability. This was made from the best available copy. Neither the United States Government nor any agency thereof, nor Battelle Memorial Institute, nor any of their employees, makes any **warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights.** The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DECLASSIFIED

HW-77338

72

July 12, 1963

GENERAL ELECTRIC

HANFORD ATOMIC PRODUCTS OPERATION - RICHLAND, WASHINGTON

X

RESTRICTED

THIS DOCUMENT CONTAINS UNCLASSIFIED DATA
IN THE ATOMIC ENERGY ACT OF 1954
TRANSMITTAL OR DISCLOSURE OF
CONTENTS IN ANY MANNER TO AN UNAUTHORIZED
PERSON IS PROHIBITED.

TITLE

EVALUATION OF THE B-CASK IN ACCORDANCE WITH
PROPOSED REGULATIONS OF THE AEC AND ICC FOR
OFF-SITE SHIPMENTS OF IRRADIATED BISMUTH

☐ OTHER OFFICIAL CLASSIFIED INFORMATION

THIS MATERIAL CONTAINS INFORMATION AFFECTING THE NATIONAL DEFENSE OF THE UNITED STATES WITHIN THE MEANING OF THE ESPIONAGE LAWS, TITLE 18, U. S. C., SECS. 793 AND 794, THE TRANSMISSION OR REVELATION OF WHICH IN ANY MANNER TO AN UNAUTHORIZED PERSON IS PROHIBITED BY LAW.

AUTHOR

Glenn E. Peck

DOING FILE
CIRCULAR COPY
RECEIVED 10 27 1964
10 27 1964
RECEIVED

THIS DOCUMENT MUST NOT BE LEFT UNATTENDED OR WHERE AN UNAUTHORIZED PERSON MAY HAVE ACCESS TO IT. WHEN NOT IN USE, IT MUST BE STORED IN AN APPROVED AND LOCKED REPOSITORY WITHIN AN APPROVED GUARD AREA. WHILE IN YOUR POSSESSION AND UNTIL YOU HAVE OBTAINED A RECEIPT FROM THE ISSUING OFFICE, IT IS YOUR RESPONSIBILITY TO KEEP IT AND ITS CONTENTS WITHIN THE LIMITS OF THIS PROJECT AND TO PREVENT ANY UNAUTHORIZED DISCLOSURE. ITS TRANSMITTAL TO ANY OTHER STORAGE AT YOUR PLACE OF RESIDENCE IS PROHIBITED. IT IS NOT TO BE DUPLICATED. IF ADDITIONAL COPIES ARE REQUIRED, OBTAIN THEM FROM THE RELATED ISSUING OFFICE FILE. ALL PERSONS READING THIS DOCUMENT ARE REQUESTED TO SIGN IN THE SPACE PROVIDED BELOW.

[illegible]

DECLASSIFIED

(CLASSIFICATION)

DECLASSIFIED

HW-77338

This document classified

by James M. Keene

This document consists of

31 pages. No. 12 of
24 copies. [REDACTED]

EVALUATION OF THE B-CASK IN ACCORDANCE WITH
PROPOSED REGULATIONS OF THE AEC AND ICC FOR
OFF-SITE SHIPMENTS OF IRRADIATED BISMUTH

by

Glenn E. Peck

Plant Design Unit
Design Engineering Subsection
FACILITIES ENGINEERING SECTION

July 12, 1963

Classification Cancelled and Changed To

DECLASSIFIED

By Authority of RM-Iten

CG-PR-2, 3-22-94

By G. E. Savary 4-1-94

Verified By DK Hanson, 4-15-94

DISTRIBUTION

1. JW Ballowe	13. GE Peck
2. RW Bown	14. CA Priode
3. LA Carter	15. T Prudich
4. AE DeMers	16. OC Schroeder
5. HW Heacock	17. ML Smith
6. PC Jerman	18. EC Watson
7. RT Jessen	19. LL Zahn
8. RL Junkins	20. Records Center
9. AR Keene	21. 300 Area Files
10. LM Keene	22. CP Doriss
11. CG Lewis	23. Extra
12. DW McLenegan	24. Extra

MASTER

DISTRIBUTION OF THIS DOCUMENT IS UNLIMITED

DISCLAIMER

This report was prepared as an account of work sponsored by an agency of the United States Government. Neither the United States Government nor any agency thereof, nor any of their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or usefulness of any information, apparatus, product, or process disclosed, or represents that its use would not infringe privately owned rights. Reference herein to any specific commercial product, process, or service by trade name, trademark, manufacturer, or otherwise does not necessarily constitute or imply its endorsement, recommendation, or favoring by the United States Government or any agency thereof. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

DECL

DECLASSIFIED

-2-

HW-77338

TABLE OF CONTENTS

<u>Item</u>	<u>Page</u>
I. INTRODUCTION	3
II. PURPOSE	3
III. CONCLUSIONS	3
IV. SUMMARY	4
V. DISCUSSION	5
A. Introduction	5
B. Description of the B Cask	6
C. Description of Radioactive Material	6
D. Resistance to Structural Failure	11
1. Impact	11
2. Puncture	12
3. Fire	13
4. Internal Pressure	14
E. Maintenance of Adequate Shielding	16
F. Provision for Heat Removal	16
G. General Container Design Standards	16-19
H. Possible Modifications to B-Casks	19
I. New Design Provision Considerations	20
REFERENCES	21
APPENDIX A - Structural Calculations	22-26
APPENDIX B - Heat Transfer Calculations	27-30

LIST OF DRAWINGS AND ILLUSTRATIONS

Drawing No. H-1-474, Building No. 105 B-57 Cask	7
Figure No. 1, B-Type Off-Site Shipping Casks in the Storage Yard	8
Figure No. 2, (a) Elevation View of Stainless Steel Cask, and (b) View Showing Spider Inside the Cask	9
Figure No. 3, Casks Being Prepared for Shipment	10
Figure No. 4, Time-Temperature Rise Curve for B-Cask and Contents	15
Figure No. 5, Deceleration G's vs. Shock-Rise Time for 15 and 30-foot Drop Heights	23
Figure No. 6, Thermal Conductivity - Materials	29
Figure No. 7, Heat Transfer Rate	31

EVALUATION OF THE B CASK IN ACCORDANCE WITH
PROPOSED REGULATIONS OF THE AEC AND ICC FOR
OFF-SITE SHIPMENTS OF IRRADIATED BISMUTH

I INTRODUCTION

The growing concern of government agencies for safe shipment of radioactive materials, both in this country and in Europe, has resulted in a number of proposed regulations governing every phase of shipment including the design of the cask or container. There have been requests during the last year for increased shipments of irradiated bismuth from Hanford. This radioactive material has been shipped in the B-cask to the off-site processing plant for several years. These two factors, proposed regulations and increased demand for the product, have created a need for an engineering evaluation of the cask currently being used. While it is evident on casual inspection that the B-cask design would not meet certain requirements of the proposed regulations, it is necessary that a detailed study of the design be made to determine if modifications to the cask are practical for continued use under new regulations and whether additional casks should be of a new design as required by increased shipments of the product.

II PURPOSE

The purpose of this design evaluation study is to:

- A Evaluate the integrity of the B-cask design in accordance with criteria published in document HW-76476, which is based primarily upon proposed regulations of the Atomic Energy Commission and the Interstate Commerce Commission
- B Determine whether the B-cask can be modified for continued use if the proposed regulations are formally issued in essentially the same form as proposed.

III CONCLUSIONS

After evaluating the B-cask against the criteria of proposed regulations, it is concluded:

- A That the cask will not meet the requirements for the following reasons:
 - 1. The cask would not survive a 30-foot drop test without rupture and/or losing its cover.
 - 2. The cask would not survive a fire test without rupture of shell, loss of lead shielding, and melting and dispersion of the canned product.

DECLASSIFIED

-4-

HW-77338

- B. That fire following impact is the most critical condition to which the B-cask and its product can be subjected and that dispersion of product upon boiling would create a health hazard.
- C. That no great hazard would result from failure of cask subjected to impact conditions alone.
- D. That the B-cask could be protected from impact and fire by a protective outer container for general compliance with proposed regulations.
- E. That extensive modification of the B-cask would not be warranted, particularly, since the lead shielding thickness is marginal to inadequate.
- F. That a program be initiated to bring cask assemblies for off-site shipment of irradiated bismuth into compliance with the criteria established by document HW-76476.

IV. SUMMARY

The B-cask is used by the Irradiation Processing Department for off-site shipments of irradiated Bismuth. Each cask is nominally one foot in diameter by 18 inches high and holds 38 slugs (Bismuth cores canned in aluminum). Shipments are made in kilocurie quantities for off-site processing with the end product being Polonium 210.

This is an evaluation study of the B-cask for the shipment of Polonium 210 product only against the design criteria based on proposed regulations of the AEC and the ICC. Polonium as an alpha emitter is not hazardous for shipment except if exposed to fire; it can be dispersed by air movement following fire exposure and is a health hazard if ingested by breathing or by contaminated water or food products.

Some of the B-casks have been in service for off-site shipments since 1947, and the latest model was built approximately by 1956. There have been no failures due to the conditions of normal handling or shipping by rail express car. Since the casks have not been in an accident which would test integrity to withstand impact and fire, it is necessary to evaluate the design in accordance with the criteria imposed by proposed regulations.

Evaluation for resistance to structural failure revealed that severe impact such as a 30-foot fall on an unyielding surface would probably cause a rupture of the shell particularly if dropped on an edge where a weld-joint would be subjected to maximum stress concentration. The trunnions used for lifting the cask would be a source of puncture of the shell and shielding material if impact were against the end of the trunnion. Two stud bolts are insufficient to secure the cover under severe impact conditions. Investigation of conditions for a fire revealed that the cask wall transferred heat readily and that the lead shielding material as well as the canned product would melt. Due to the greater linear coefficient of expansion for lead over steel or stainless steel, it is expected that rupture of the shell would result with less than 500 F rise in temperature.

DECLASSIFIED

-5-

HW-77338

[REDACTED]

The most hazardous condition which could arise from a credible accident would be failure of the cask under impact followed by a fire which would melt the product and bring it to a boil. Boiling and dispersion of Polonium could be expected to begin at about 950 C (1742 F) and create the health hazard as mentioned above. ?

The shielding of 2 to 2½ inches varies according to mold of cask. Careful scheduling of decay times is required so that radiation levels will conform to the proposed regulations. It is estimated that 3.15-inches of lead would be satisfactory with five days between discharge of slugs from the reactor and loading in the cask. The shielding material would not be maintained in place as result of impact and fire.

The B-cask design apparently meets the General Container Design Standards in important features considered for off-site shipment with exceptions noted. The present cask could be protected from fire and impact and the other conditions incident to shipment if placed in a container which was fabricated of impact and fire resistant materials.

Additional or new casks would require evaluation of design on the basis of current product demand, economical use and fabrication of materials, and current and proposed regulations for licensing of casks for off-site shipment.

V. DISCUSSION

A. Introduction

This discussion of design evaluation of B-type off-site shipping casks shall follow the order of the criteria established in the document HW-76476 (1). Before beginning the design evaluation, sections B and C will furnish a description of the cask and the radioactive material for which the evaluation is based. The criteria (1) was developed primarily from proposed regulations of the AEC and the ICC Bureau of Explosives. Sections D through G cover the evaluation for meeting the criteria of proposed regulations. It is analytical from known physical characteristics of the materials and conditions and is analogous in so far as similar casks have been tested destructively or experimentally. Certain parts of the evaluation can be proven definitely only by destructive testing. Impact and fire temperatures are areas where little specific data are available; however, preliminary comparison of the B-cask characteristics indicate that this cask will fail to meet the criteria in several ways based upon reasonable assumptions. Sections H and I discuss possible modifications and new design provisions, respectively.

[REDACTED]

DECLASSIFIED

-6-

HW-77338

B. Description of the B-Cask

The first casks of this type were fabricated about 1947 from the drawing H-1-471 which is reproduced on the next page. Several of these casks are still in use even though the painted carbon steel shells are difficult to decontaminate. A later version of the cask changed the method of cover tie-down from U-bolts to two stud bolts through the cover and a more pronounced off-set design of the cover fitting into the top of the cask. The difference in cover design can be made by comparing the drawing and Figure 2. The second model was carbon steel and painted.

The latest model is identical in design to the second version except the shell is entirely of stainless steel to make decontamination easier. The difference in the various models can be noted on Figure 1 which shows the casks standing in the storage yard.

Briefly, the casks are 12-3/4 inches in diameter by 18-3/4 to 19-3/4 inches tall cylinders with lead shielding material approximately 2-inches thick between outer and inner shells. The cask weights approximately 686 pounds empty and 800 pounds loaded. The cover or lid weighs about 117 pounds.

Calculation of weights indicates that the newer models of the cask were constructed of .375-inches thick stainless steel rather than .406-inch thick carbon steel pipe of the original for the outer shell. Otherwise the use of material was similar. The newer models completely enclosed shielding material while early models had machined and exposed lead at fitting with cover, as can be noted in Dwg. H-1-471.

C. Description of Radioactive Material

The B-cask is being evaluated for irradiated Bismuth 209 encapsulated in aluminum cans or slugs with the product being Polonium 210. A hazards analysis of this material and physical and radiological property data has been reported in HW-77484 in conjunction with this evaluation. Information pertinent to this study is summarized below:

Polonium 210, an alpha emitter, is the source of radiological hazards only if the aluminum slug is ruptured and then only if the Bismuth has been heated to approximately 1742 F. Bismuth melts at 519.8 F and has the useful characteristic of contracting when melting and therefore, poses no problem of stress upon the aluminum jacket at transition from solid to liquid. The aluminum melts at about 1200 F so the interior of the cask must be kept comfortably below this temperature--a minimum of 300 F for compliance with criteria. As long as the slug or aluminum capsule remains sealed, thus containing the Bismuth, there will be no radiological hazard from dispersion of Polonium 210. Since Polonium could be dispersed in the event of a creditable accident, it is necessary to classify the material as dispersible.

WHERE EXTENSIVE
Y-OR ARCHIMEDIAN
IS (SHEET)
HAVE ONE
TOVOLUME ONLY.

WHERE SMOOTH CONTACT
SPACE OF 1/8\"/>

DETAIL 'A' - CONTAINER CORE

FULL SCALE

NOTE: FABRICATE CONTAINER OF 1/8\"/>

SECTION 'B-B'

SECTION 'D-D'

SECTION 'C-C'

CLASSIFICATION
NONE

SCALE: HALF & FULL SIZE

3902

HANFORD ENGINEER WORKS

BLDG #105
B-57 CASK
EP 105-397

REFERENCE DRAWINGS	REVISIONS
<div data-bbox="428 1935 512 1979">H-1-474</div> <div data-bbox="512 1935 707 1979">SHIPPING CASE</div> <div data-bbox="512 1979 707 2004">TITLE</div>	<div data-bbox="758 1866 809 1911">Added Note</div> <div data-bbox="809 1889 997 1922">Added V Grooves</div> <div data-bbox="809 1922 1031 1955">Removed Reinforcing Loop</div> <div data-bbox="809 1955 980 1988">Gen. Revision</div> <div data-bbox="809 1988 980 2004">DESCRIPTION</div> <div data-bbox="1014 1935 1151 1979">BY DATE APP'D</div>

<div data-bbox="1151 1911 1219 1955">H</div> <div data-bbox="1219 1911 1287 1955">S.P.S.</div> <div data-bbox="1287 1911 1356 1955">R</div> <div data-bbox="1356 1911 1424 1955">K.M.</div> <div data-bbox="1424 1911 1492 1955">J.M.</div>	<div data-bbox="1151 1955 1219 2004">DATE</div> <div data-bbox="1219 1955 1287 2004">1/2/42</div> <div data-bbox="1287 1955 1356 2004">1/2/42</div> <div data-bbox="1356 1955 1424 2004">1/2/42</div> <div data-bbox="1424 1955 1492 2004">1/2/42</div>	<div data-bbox="1151 2004 1219 2048">DRAWN BY</div> <div data-bbox="1219 2004 1287 2048">E. J. JONES</div> <div data-bbox="1287 2004 1356 2048">CHECKED</div> <div data-bbox="1356 2004 1424 2048">G. J. JONES</div> <div data-bbox="1424 2004 1492 2048">DATE</div> <div data-bbox="1492 2004 1561 2048">1/2/42</div>
---	---	--

HW-474

UNCLASSIFIED

-8-

HM-77338

FIGURE NO. 1
B-TYPE OFF-SITE SHIPPING CASKS
IN THE STORAGE YARD

ALICE RICHARD WASH

UNCLASSIFIED

ELEVATION VIEW OF STAINLESS STEEL CASK (a)

VIEW SHOWING SPIDER INSIDE THE CASK (b)

FIGURE NO. 2

FIGURE NO. 3
CASKS BEING PREPARED FOR SHIPMENT

DECLASSIFIED

-11-

HW-77338

Impurities in the aluminum jacket as irradiated are the source of radiation which makes the lead shielding of the cask necessary to protect people and equipment from exposure during shipment. The hazard from exposure is not lethal even if the cask were breached, providing the slugs remained intact. The radiation would be about 5 R at contact and 50 mr at one-half meter. These are exposure estimates but should be accurate enough for establishing the order of magnitude.

D. Resistance to Structural Failure

1. Impact

Evaluation of the B-cask design under conditions of impact as described by HW-76476 (1) shall be generally empirical rather than by theoretical means. Faires (2) supports the opinion that calculations cannot be used reliably for prediction of impact results. Although impact testing of casks has not been extensive, the reported results from these tests will aid this evaluation.

Three orientations of the cask for drop-test or impact are possible with a cylindrical type such as the B-cask to give maximum stresses: side, edge or corner, and top or bottom. Also, it is necessary to evaluate the effect of protruding parts of the cask such as lid-lifting eye-bolt or cask lifting trunions.

Shappert (3) reports that ORNL experienced weld cracking for corner drops for a drop height of 16 feet with considerable displacement of shielding material due to impact. From the B-cask drawing, the weld detail reveals a small cross-sectional area for weld material. The concentration of stresses from a corner drop could be expected to produce corner cracking from either a 15 or 30-foot drop test.

In making side-drop tests, Shappert (3) reported strains which followed Roark's (4) formula for thick-walled cylinders but of lesser magnitude than calculated. Using Roark's formula as shown in Appendix A.1, the calculated stress was 15,178 psi on the inner shell of the cask for a 30-foot drop height. Since the cask has lead shielding material between the inner and outer shells, it is thought that the free-flow property at or above dynamic stress of 12,000 psi (5) would distribute the stress somewhat and that the actual impact stress would be somewhat below the calculated result above. This analysis would tend to confirm the lesser permanent deformations compared to that calculated by Shappert.

DECLASSIFIED

-12-

HW-77338

The dynamic loading which the cask must withstand is dependent upon the deceleration which is in turn dependent upon the nature of the impact, the materials involved, and the velocity at impact. It is convenient to express dynamic loading in terms of gravity or G's. From Reference (6) the number of G's can be computed from various empirical shock-rise times. The calculated G's for a 30-foot fall by this method gives a deceleration of 1368 G's. This compares favorably with recorded shocks of 1100 to 1400 G's during drop test by ORNL.

The criteria (1) requires that the cover fastenings withstand a force 60 times its own weight for a period of not less than 16 milliseconds or if the cover projects above the cask, as it does in the case of the B-cask, 15 times the loaded weight of the cask. Such requirements would not impose stresses beyond the limits of the bolts as per calculations in Appendix A.1. However, dynamic loading imposed by a drop test is estimated to be approximately 684 G's and therefore, requiring more bolting strength than indicated by the proposed regulations. It has been calculated that eight bolts of the same size would be required to meet dynamic stresses without failure.

The eye-bolt on the cover of the B-cask is designed only for lifting the cover. The loaded cask is lifted by trunions on each side of the cask. An alternate orientation for drop tests would be so as to impact the weight of the cask directly on the end of the trunion ($1\frac{1}{4}$ -inch D). From reported tests of drops on bars of this diameter it is expected that the cask would be punctured and the real possibility that the contents of the cask would also be damaged. The unprotected eye-bolt would probably fail before causing extensive damage to the cask under impact. The protruding eye-bolt and trunions make protection of the cask more difficult.

In summary, the present B-casks have been used for a number of years without failure by ordinary handling. There is no record of a serious accident involving these casks. From the assumptions made and comparable testing programs by others, it seems certain that destructive testing would reveal that the cask would not meet the impact requirements of the proposed regulations.

2. Puncture

Criteria for puncture was set at a force equal to 30 times the weight of the loaded container over any circular area 6-inches in diameter and the duration of the applied force is assumed to be not less than 16 milliseconds. Using these conditions, shear stress was found to be 3,395 psi by calculations in Appendix A.2. Stainless steel or mild steel would be safe for the criteria condition which computes out to be a fall from 44.4-inch height.

DECLASSIFIED

-13-

HW-77338

This portion of the criteria as contained in the proposed regulations is thought to be highly controversial for several reasons since puncture by a 6-inch cylinder arbitrarily penalizes larger casks where the difference in weight places increasing burden of stress with increasing weight. Although the B-cask meets the criteria as stated for puncture, it is thought that the trunions on each side of the cask offer classic examples of possible puncture under impact accident conditions.

Calculations were made for a 30-foot fall with the $1\frac{1}{4}$ -inch diameter trunion normal to impact surface for rigid stopping condition and the less stringent condition of bending allowance of outershell and displacement of lead shielding material. The analysis for these conditions produced stresses in excess of 150,000 psi which would clearly indicate failure of the outer shell and puncture.

Confirmation of weakness of cask for resistance to puncture under drop test conditions may be found as reported by Thisell of du Pont, Shappert of ORNL, Clarke and Onderko of Franklin Institute, and McLenegan, Smith, Ripperger, and Breen of Hanford and the University of Texas in Reference (7).

3. Fire

Before applying conditions set forth in the Criteria (1) it is necessary to classify the material shipped and the method of shipment. According to Smith and Prevo (8) the product is dispersible at a temperature of 950 C (1742 F); therefore, we must classify the source as dispersible for it will be shown that such temperatures are possible. It is also within consideration of a credible accident to have fire following impact and from the discussion of impact previously it can be seen that loss of shielding material through cracks developed by impact is a case of failure to meet the criteria. While the criteria is more stringent than the proposed regulations it is considered that petroleum products fire temperatures of about 2000 F are more representative of cask shipping conditions than the standard fire curve.

Calculations were made of heat rise and heat transfer to the cask (see Appendix B for detailed calculations) for a fire which would produce a temperature of 2000 F to all cask surface exposed. Certain broad assumptions were made in order to simplify the calculations while gaining an order of magnitude picture of the effects of fire. For example, the heat transfer was considered only for area at right angles to the internal volume of the cask

DECLASSIFIED

-14-

HW-77338

for both sides and the end exposed. The corner area not considered was assumed to have no appreciable effect on the heat transferred to the cask contents and to be off-set by dissipation through the end not exposed. Further, it was assumed that all heat transferred to the inside of the cask would be dispersed evenly through the cask. This last is, of course, impossible since those slugs in contact with the sides of the cask or the end of the cask would be heated more rapidly than those in rows not touching the cask, but it is thought that conduction and radiation of heat to air free to circulate would keep the temperature gradient low from the center of the product container out to the edges.

The time--temperature rise curve (Figure 4) illustrates the results of the calculations for heat transferred to the cask and its contents. As can be noted, the cask contents will reach 900 F in less than six minutes. It is desirable to keep a safe margin below the melting point of aluminum which contains the radioactive product. In less than 16 minutes 1742 F would be reached and polonium would begin to disperse or be driven off and at increased rate with increased temperature. Thus, if the above assumptions and calculated heat transfer rates are valid, the cask does not meet the requirements of the criteria for withstanding a two-hour fire. If the heat transfer rates used were five times higher than actual, the cask would still fail to meet the criteria for fire protection. Increased temperatures of a fire also have an effect due to the differences in linear expansion coefficients between lead (16.3×10^{-6}) and 304 stainless steel (9.5×10^{-6}). Considering the stress $s = \epsilon E$, where ϵ is strain developed, for a 500 F rise in temperature the stress would be 98,600 psi. Though not strictly applicable, it is indicative of high stresses developed when a metal or non-metal is restrained from expansion. Failure of the stainless steel container or of its welds is possible due to expansion of lead.

Drawing H-1-471 shows silver solder for connection of drain to the outer shell. This solder would not be expected to hold much beyond 1000 F.

The above points made in discussing the effects of fire on the B-cask, clearly indicate that fire protection in the form of insulation will be necessary if the cask is to meet requirements of the criteria.

4. Internal Pressure

As presently used, the B-cask doesn't offer any problem to relieving any internal pressure which might develop since the

1900

1800

1700

1600

1500

1400

1300

1200

1100

1000

900

800

700

600

500

400

300

200

100

0°

1

2

3

4

5

6

7

8

9

10

11

12

TIME, MINUTES

Product begins boiling at 1742F

14

15

16

Aluminum melting

Lead melting

Bismuth
melting

Figure No. 4

TIME - TEMPERATURE RISE CURVE
B-CASK AND PRODUCT CONTENTS

To = Constant 2000F

Ti = 100F initially

UNCLASSIFIED

DECLASSIFIED

-16-

HW-77338

cover is secured by only two bolts. The product doesn't offer problems such as liquid products might due to expansion or vaporization. The present design is poor from the standpoint of sealing the cover to the cask body and requires a tape seal as illustrated in Figures 1 and 3 to keep moisture out.

E. Maintenance of Adequate Shielding

The B-cask as presently designed requires a decay period of at least ten days before the product can be placed in the cask to give a measurement of 10 mr or less from a measurement point one meter distance from the exterior of the cask. In Reference (8) it is recommended that the optimum thickness of lead is 3.15-inches for a decay time of five days. Evaluation of thickness on the basis of current requirements and the analysis of radiological properties should be made in the event new or additional casks are designed.

An offset in the cover of the B-cask appears to be adequate to prevent beaming of radiation to the exterior. Shielding cannot change configuration in the cask under normal conditions. The inner shell of the cask might be displaced or bent inward in the event the lead shielding were melted although it is supported by the spider and contained slugs of product. There are no controlled voids in the B-cask, and, as has been shown under Section D for structural design, it is possible for the cask to be breached. In the event of a creditable accident followed by fire, shielding would be lost. The loss of the shielding would create a contamination problem but would not be considered hazardous unless the slug jacket failed and the product boiled.

F. Provision for Heat Removal

As noted in Reference (8) the heat generated by this source is negligible, the approximate 8 BTU per hour would be easily dissipated by the earth in the event the cask were buried by a landslide. No provision for heat removal is necessary.

G. General Container Design Standards

1. Regarding the cask as a simple beam in the manner specified by criteria, it is found that the outer shell alone has a factor of safety exceeding 50 when so considered without taking into account the added stiffness contributed by the inner shell and the lead shielding material.
2. The cask is capable of withstanding vibration incidents to shipment without impairing the integrity of the closure or of the cask itself. This has been demonstrated by the past history of the cask in being shipped over a period of years without failure.

DECLASSIFIED

-17-

HW-77338

The general proportion of the cask and relationship of wall thickness to size of the cylinder are such as to preclude the possibility of resonant vibration as incidental to rail shipment.

3. The cask is sealed with tape as shown in Figure No. 3. This seal is applied to prevent leakage of water into or out of the cask and is not intended to provide evidence of tampering. Although the tape used is thought to be difficult to remove and reapply without leaving evidence of the fact, there is nothing to prevent new tape of the same type being applied without detection. At present the shipments are accompanied by a courier and therefore tampering is not a problem. If a railroad-type seal becomes necessary, one of the stud bolts holding the cover on can be drilled with a hole just above the hex nut for insertion of a wire to which a tamper proof seal of the railroad-type can be applied.
4. The materials of which the cask were fabricated are satisfactory in that there is no significant chemical, radiolytic, galvanic, or other reaction between them and the material carried in the cask. The wall thickness of the outer shell exceeds the minimum requirements of the Bureau of Explosives contained in Table I of the Criteria (1).
5. This section of the criteria, as in other parts, considers the design for a new cask rather than for an old or existing one. The welds on the casks, by inspection, appear to be of excellent workmanship. It would be difficult, if not impossible, at this date to find records indicating the standard to which the welds were made. Recourse to destructive testing of welds does not seem justified. The melting point of welding and brazing materials would be over 1000 F but not enough is known of fabrication details to make any comment as to more stringent requirements of a fire. (See the section on fire protection for specific remarks and conclusions in this regard.)
6. The casks were well designed for decontamination and there are no non-draining crevices or inaccessible places which would prevent efficient decontamination.
7. The cask is provided with an eye-bolt for lifting the cover only and two trunions on the cask for lifting the cask or loaded assembly. These attachments are generally adequate for normal handling but leave something to be desired for convenience of tie-down as can be noted on Figure No. 3.

DECLASSIFIED

-18-

HW-77338

8. Any device which can be used for tie-down of the cask must withstand a static force with vertical component equal to three times the weight of the cask and with horizontal component equal to ten times the weight. The calculated resultant force (see Appendix A.4) would equal 8352 pounds. The eye-bolt on the cover is fabricated of 3/4-inch stock and is strong enough to withstand the above combined force if no factor of safety is used; however, if the customary factor of six is applied, the eye-bolt would be good for only 1953 pounds. While the method used in the tie-down of the casks is awkward and time consuming, it is apparently adequate as the casks are now shipped. The eye-bolt was not intended for the use to which it is subjected.
9. Cask trunions are capable of lifting six times the weight of the loaded cask without exceeding the yield strength. See Appendix A.5.
10. The eye-bolt yield strength will not be exceeded for either (1) six times the weight of the lid, or (2) three times the weight of the loaded cask. See Appendix A.6.
11. The only holes drilled in the body are for two bolts at the top and for the drain at the bottom. The bottom drain is silver soldered in place and can be considered sensitive to heat over 1000 F. Although a drawing for the later casks with the two stud bolts has not been found, it seems most probable that the bolts terminate within a boss pad. The change in off-set design would also account for a portion of additional height.
- Since it was determined earlier that two bolts were inadequate to meet the criteria, this discussion is academic. The closure around the bolts appears to have been welded and therefore is as strong as the welds at points where light-gage metal is used such as the inner shell.
12. It is not necessary to equalize the internal pressure of the cask under present conditions nor can such be the case for this product as long as suitable protection for the cask is provided.
13. Vents or pressure relief devices are not required for this cask.
14. This cask is not being evaluated for shipment of irradiated iodine or where I^{131} fission product could exist.
15. Since devices of Item 12 above are not applicable, no evaluation is required under this standard design condition.

DECLASSIFIED

-19-

HW-77338

16. No applicable valves are used with this cask.
17. The drain pipe is fitted with a plug. This has been a positive closure in Hanford experience but is not definitely locked. This drain has not been in use for some time since slugs are loaded dry instead of under water as was the case when the B-casks were designed.
18. The eye-bolt and the lifting trunions extend out from the cask or above it as the case may be. Therefore these cask parts are not protected from mechanical damage and in the event of a fire in addition to impact could result in radiation dose rate of exposure greater than that allowed by the criteria.
19. Evaluation comment to this item is essentially the same as that for Item 17.
20. The drain pipe used in the cask would not appear to be damaged by the lead or conditions of transport except in the event of an accident. Destructive deformation of the cask would result before ? failure of this portion of the cask.

H. Possible Modifications to B-Casks

The possible modifications which might be made to the B-casks in current use are of two types: (1) those which require no physical modifications to the cask, and (2) alterations to the cask. It is beyond the scope of this report to make a cost study of extent of suitable modifications which could be provided against the cost of design and fabrication of a new cask which would meet all the provisions of the criteria.

From a practical standpoint, modifications which do not require physical alteration of the casks offer the best avenue of approach even if only for temporary relief. The two factors which have the greatest effect on the evaluation of design integrity are impact and fire. Both accident conditions can be guarded against by placing the present cask inside another container which surrounds the cask with insulating and impact-resistant materials. Since the B-cask is rather small dimensionally, it is possible that the outer container could be built on the egg-crate idea to handle two, four, or more casks in one container for simplification of tie-down and loading.

Alterations to the cask such as the addition of bolts to secure the cover, reinforcing inner shell for shielding material containment, grooving for metal o-ring seal, etc., would require essentially a new cask and would still require protection against impact and fire. Therefore, any but minor alterations to cask exteriors seem impractical.

DECLASSIFIED

-20-

HW-77338

I. New Design Considerations

Should current requests for polonium exceed current B-cask capacity, additional casks will be required and these should be fabricated to a new design to conform with proposed regulations. The size, shielding thickness, and materials would depend on quantities to be shipped and the frequency of shipment, the handling facilities available at both ends of the shipment, fabrication economics versus weight considerations, and the requirements for licensing under government agency regulations.

The manner of handling and loading casks has changed since the B-cask was fabricated for the shipment of irradiated Bismuth (Polonium). Originally, the cask was loaded under water and the side-lifting trunnions were necessary to movement into and around the metal storage basin. The slugs of irradiated product are now loaded dry with long-handled tongs. Therefore, the side trunnions could be eliminated if the design of the cover provided lifting devices for this purpose.

Cover design should be such that lifting eyes or devices will be protected from mechanical impact if the cover is exposed. The cover and all exterior parts of the cask should be designed for ease of decontamination with no crevices to trap moisture. Closures should be sealed so that no entrapment of liquid is possible.

The method of protecting against impact with an expendable outer container would seem appropriate to the design of new B-casks. The addition of insulation required for protection from fire, should be included in the design.

Glen E. Peck

Plant Design Unit
Design Engineering Subsection

GE Peck:be

DECLASSIFIED

HW-77338

REFERENCES

- (1) Peck, G. E., "Design Criteria for Evaluation of Off-Site Shipping Casks in Current Use by IPD", HW-76476, May 8, 1963.
- (2) Faires, V. M., "Design of Machine Elements", The MacMillan Co., 3rd Edition, 1955.
- (3) Shappert, L. B., "Cask Test Program at ORNL", TID-7635, May, 1962.
- (4) Roark, R. J., "Formulas for Stress and Strain", McGraw-Hill Book Company, 3rd Edition, 1954.
- (5) Goldsmith, Werner, "Impact", Edward Arnold (Publishers) Ltd., London, 1960.
- (6) Magner, R. T., "design for Shock Resistance", PRODUCT ENGINEERING, December 10, 1962.
- (7) "Summary Report of AEC Symposium on Packaging and Regulatory Standards for Radioactive Materials", TID-7651, December 5, 1962.
- (8) Smith, M. L. and Prevo, P. R., "A Hazards Analysis for Kilocurie Shipments of Irradiated Bismuth", HW-77484, April 30, 1963.
- (9) Maleev, V. L., "Machine Design", Int. Text Book Co., Rev. 1st Edition, 1946.
- (10) McAdams, W. H., "Heat Transmission", McGraw-Hill Book Co., 3rd Edition, 1954.
- (11) Manual, Steel Construction, AISC, 4th Edition, 1945.

DECLASSIFIED

APPENDIX A

STRUCTURAL CALCULATIONS

A.1 Impact

- a. Side-drop from 30 feet for dispersible source.

From Magner (6) : $G = \frac{72}{t} \sqrt{h}$, where t = shock rise time, milliseconds
 h = drop height, inches
 G = acceleration

When $t = 16$ milliseconds, $G = \frac{72}{16} \sqrt{30 \times 12} = 85.6$

When $t = 01$ milliseconds, $G = \frac{72}{1} \sqrt{360} = 1368$

Figure 5 on the next page is a graphical plot of this formula for drop heights of 15 and 30 feet showing the variation in G's according to impact rise times.

To determine impact stresses use Roark's (4) formula for thick-walled cylinders: $s = \frac{K 2P}{\pi b}$, where: K = empirical constant, ratio ID:OD
 P = load imposed per unit length
 b = outer radius

Calculate: $P = \frac{G's \times \text{cask weight}}{\text{Cask length}}$

When $G = 85.6$ for 16 milliseconds stop-time, $P = \frac{85.6 \times 800}{19} = 3,605$

When $G = 684$ for 2 millisecond stop-time, $P = 684 \times 42.11 = 28,803$

Substitute in Roark's formula for K of 16, $b = 6.375$, and $P = 3605$

$s = \frac{16 \times 2 \times 3,605}{\pi \times 6.375} = 1.5977 \times 3,605 = 5,760 \text{ psi}$

Use $P = 28,803$ instead of 3,605 and $s = 1.5977 \times 28,803 = 46,019 \text{ psi}$

Using the shock rise time given by the criteria produces a safe stress by the above analysis while use of more stringent data from Reference (6) produces a stress of 46,019 psi on the inner shell. The stress at point of impact will be at least this high on the outer shell, therefore an indication of failure for carbon steel and possible failure for stainless steel particularly at a weld joint.

UNCLASSIFIED

-23-

HW-77338

UNCLASSIFIED

- b. The cover and bolts withstand F equal (1) 60 X weight of cover, and
 (2) 15 X weight of loaded cask. $F(1) = 60 \times 120 = 720 \text{ lbs.}$
 $F(2) = 15 \times 800 = 12,000 \text{ lbs.}$

Since the cover extends above the top of the cask body, the more stringent F(2) applies.

From Maleev (9) : the size factor, $e_{ez} = 1 - 0.4(1 - \frac{S_{e3}}{S_e})(h - 0.5)$

Substitute $\frac{S_{e3}}{S_e} = .85$ and $h = .625$, and $e_{ez} = .9925$

Design stress $S_d = \frac{S_e \times e_{ez}}{n}$, where $S_e = 40,000 \text{ psi}$
 $n = 1.5$

Therefore, $S_d = \frac{40,000 \times .9925}{1.5} = 26,467 \text{ psi}$

Bolt Loading = $S_d \times \text{root area at bolt threads} = 26,467 \times .202 = 5,346 \text{ lbs.}$

Total loading for two bolts = 10,692 lbs.

The above meets requirements of F(1) and fails for F(2) which is controlling for the criteria.

As shown in part a above, the shock-rise time is probably much higher than that allowed in the Criteria; therefore, assuming a G-684 and load factor (Lf) transmitted to bolts is .5, the number of bolts can be calculated:

$$N = \frac{G \times W_c \times L_f}{L_d} \quad \text{where:} \quad \begin{array}{l} N = \text{Number of bolts} \\ W_c = \text{Weight of cover} \\ L_d = \text{Design load per bolt} \end{array}$$

$$N = \frac{684 \times 120 \times .5}{5,346} = 7.67,$$

Use 8 - 5/8" diameter bolts

A.2 Puncture

Criteria: Normal to exterior loading equal to thirty times the weight of the loaded cask applied over the area of a six-inch circle.

$$S_s = \frac{30 \times W}{A_s} = \frac{30 \times 800}{6 \times \pi \times .375} = \frac{24,000}{7.07} = 3,395 \text{ psi, safe loading according to criteria.}$$

DECLASSIFIED

-25-

HW-77338

From A.1.a, substituting in $G = \frac{72}{t} \sqrt{h}$

$$h = \left(\frac{30 \times 16}{72} \right)^2 = 44.4 \text{ inches, which indicates that criteria for puncture is less stringent than for impact.}$$

Note: Ss would increase in direct proportion to the weight of the cask, thus penalizing the heavier cask.

Investigating puncture condition when B-cask is dropped on trunion, normal to unyielding surface. Assume some bending of outer shell so that shock-rise time would be 4 milliseconds and from Figure 5, G would equal 342; calculate Ss:

$$Ss = \frac{342 \times 800}{1.25 \pi \times .375} = 185,794 \text{ psi (Failure or Puncture)}$$

For comparison, Ss for 16 millisecond stop time equals 46,448 psi which might not puncture the outer shell; however, something has to be displaced to give this relatively slow shock rise time, and it is assumed that the lead would be displaced so that radiation level would be sharply increased.

- A.3 Consider cask as simple beam, end supported, apply force ten times loaded cask weight uniformly distributed.

From Reference (11), pp. 351-358:

$$M_{\max} = \frac{W \times l}{8}, \quad f = M \times \frac{c}{I} = \frac{M}{S}, \quad S = \frac{I}{c}$$

$$\text{and } S = .098175 \frac{d^4 - d_1^4}{d} = .98175 \frac{(12.75)^4 - (12)^4}{12.75} = 43.82$$

$$M = \frac{800 \times 10 \times 19.75}{8} = 19,750$$

$$f = \frac{19,750}{43.82} = 450.71 \text{ psi, this is a very small stress and leaves a margin of at least 50 as a factor of safety without counting the added stiffness contributed by the lead shielding and the inner shell.}$$

- A.4 Any device which can be used for cask tie-down during shipment should withstand a static force with three times the weight for a vertical component and ten times the weight for a horizontal component.

$$V = 3 \times 800 = 2400 \text{ lbs.}$$

$$H = 10 \times 800 = 8000 \text{ lbs.}$$

$$F = \sqrt{2400^2 + 8000^2} = 8352 \text{ lbs.}$$

Apply above resultant force to the 3/4" stainless eye-bolt on the cask cover. (See Figure 3 for current usage).

DECLASSIFIED

-26-

HW-77338

From Faires (2) p. 135:

$$F_c = \frac{S_y}{6} (A_s)^{3/2} \quad \text{p. 35, } S_y \text{ for 304 SS} = 40\text{Ksi}$$

$$F_c = \frac{40,000}{6} (.442)^{3/2} = 1953 \text{ lbs. (unsafe since } F \text{ required is larger than } F_c)$$

However, the Faires equation contains a factor of safety of 6 and if this is neglected, $F_c = 11,718$.

On this basis, factor of safety: $n = \frac{F_c}{F} = \frac{11,718}{8,352} = 1.4$, adequate for not exceeding yield strength

- A.5 Any device designed for lifting casks should be capable of lifting six times the weight of the loaded cask.

Area of strap holding end of trunion = $3/2 \times 1/4 = .375$ sq. in.

Area of $1\frac{1}{4}$ " D trunion bar = $(3/4)^2 \frac{\pi}{4} = 1.227$ sq. in.

Area of $3/4$ " D trunion bar in the strap = $.4417$ sq. in.

Strap has smallest area so calculate S_s on the basis of $.375$ sq. in. Assume that $.75$ of load on one trunion applies to this area.

$$S_s = \frac{6 \times 800 \times .75}{2 \times .375} = 4800 \text{ psi, Safe: will not fail for the above conditions.}$$

- A.6 Any device which is attached to the cask cover for the purpose of lifting the cover shall be capable of satisfying (1) six times cover weight, and (2) three times loaded cask weight.

$$(1) 6 \times 117 = 702 \text{ lbs.}$$

$$(2) 3 \times 800 = 2400 \text{ lbs., Governing condition}$$

$$\text{Eye-bolt, } S_d = \frac{2400}{.4417} = 5434 \text{ psi, safe for the above conditions.}$$

DECLASSIFIED

-27-

HW-77338

APPENDIX B

HEAT TRANSFER CALCULATIONS

D.1 Heat transferred to B-cask and contents and resultant temperature rise. Assume the most rigid conditions from the criteria; i.e., dispersible source in the cask exposed to petroleum products fire with the cask sitting in a pool of this inflammable liquid.

a. Calculate transfer rate through cylindrical sides from McAdams (10):

$$(B1) \quad G_s = \frac{\Delta t}{\left(\frac{X_a}{K_a A_a} \right) + \left(\frac{X_b}{K_b A_b} \right) + \left(\frac{X_c}{K_c A_c} \right)}$$

where: X = thickness, feet
K_b = transfer coefficient
A = Area, sq.ft.

$$(B2) \quad \text{Mean Diameter, } D_m = \frac{D_2 - D_1}{\ln \frac{D_2}{D_1}}$$

D_{ma} (Inner Shell) = 8.0802
D_{mb} (Lead) = 9.9356
D_{mc} (Outer Shell) = 12.2770

Substitute appropriate values in (B1) above and solve for denominator:

Use K from Figure 6 on next page:

$$G_s = \frac{\Delta t}{\left(\frac{.0625}{12} \right) + \left(\frac{2.000}{12.00} \right) + \left(\frac{.375}{12} \right)} = \frac{\Delta t}{.264} = \Delta t \times 3.78787$$

$$G_s = \Delta t \text{ for 14" cask eff. } L \times 4.41916 = 8400 \text{ BTU/Min for } \Delta t = 1900 \text{ F.}$$

b. Calculate transfer rate through exposed end of cask:

$$(B3) \quad G_e = \frac{1}{A} \left[\frac{X_a}{K_a} + \frac{X_b}{K_b} + \frac{X_c}{K_c} \right] \Delta t$$

Substitute appropriate values in (B3):

$$G_e = \frac{1}{(60) \cdot .349} \left[\frac{.0052}{10} + \frac{.1667}{18} + \frac{.0313}{12} \right] \Delta t = \frac{\Delta t}{.03547(60)} = \Delta t \times .46988$$

DECLASSIFIED

-28-

HW-77338

$G_e = 1900 \times .46988 = 893$: round to 900 BTU/Min.

c. Total transfer to cask and contents is:

$G_t = G_s + G_e = 8400 + 900 = 9300$ BTU/Min. for $\Delta t = 1900$ F.

B.2 Calculate heat rate for product and cask per degree F:

<u>Material</u>	<u>Specific Heat</u>	<u>Weight Lbs.</u>	<u>Heat Rate BTU/Degree F</u>
Aluminum	.218	7	1.526
Bismuth	.030	114	3.420
Lead	.031	570	17.670
Stainless Steel	.120	108	12.960
		TOTAL	35.576 - say 36 BTU/°F

B.3 Calculating temperature rise of product and cask assuming no dissipation through the bottom of the cask except that which will balance heat input not accounted for in the above calculations.

From B.1.c, total transfer for $t = 1900$ F equals 9300 BTU

From B.2, the heat required to raise product and cask 1 F is 36 BTU

Therefore, Temperature Rise = $\frac{9300}{36} = 258$ degrees F

But the above is based upon a constant rate of heat transfer and the rate changes as the temperature difference changes; therefore, calculations for heat transfer rate should be made for temperature differences starting with 1900 F down through 100 F at 300 F intervals. An arithmetic average can be used for the heat transfer rate between two temperatures for close approximate results in determining time required for this temperature rise or change.

B.4 Calculation of heat transfer rate for various temperature differences indicated in the paragraph above by methods outlined.

F	100	400	700	1000	1300	1600	1900
q rate, BTU/M	489	1956	3422	4889	6356	7823	9289
q rate, rounded	500	2000	3500	4900	6400	7800	9300

Plot the above rounded q rates against product temperatures so that arithmetic averages can be taken between convenient temperatures. Data so plotted are contained on Figure 7 on the next page.

DECLASSIFIED

-30-

HW-77338

B.5 Calculate elapsed time to reach various temperatures with averages taken from Figure 7 and using results of B.2 calculation.

<u>Step</u>	<u>Product Temp. F</u>	<u>Elapsed Time, Min.</u>
Start	100	0
Rise to	520	1.84
Bismuth melted at	520	2.20
Rise to	622	2.72
Lead melted at	622	3.54
Rise to	920	5.30
Rise to	1220	7.63
Aluminum melted at	1220	7.93
Rise to	1520	11.31
Rise to	1742	15.56

The above information is plotted on Figure 4.

B.6 Heat generated by the product from (8) :

$$.558 \text{ cal/sec/cask} \times \frac{3600}{251.996} = 7.9715 \text{ BTU/Hr.}$$

10-11-14

10-11-14

10-11-14

DATE

FILMED

6/14/94

END