

9 1 1 2 1 7 2 1 3

LEGAL 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, nor any of their contractors, subcontractors or their employees, makes any warranty, express or implied, or assumes any legal liability or responsibility for the accuracy, completeness, or any third party's use or the results of such use 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 or its contractors or subcontractors. The views and opinions of authors expressed herein do not necessarily state or reflect those of the United States Government or any agency thereof.

This report has been reproduced from the best available copy.

Printed in the United States of America

DISCLM-2.CHP (1-91)

ACKNOWLEDGEMENTS

During the course of this assignment the Container Weld Advisory Committee encountered many professional individuals who extended a full measure of cooperation and hospitality to each committee member. The committee greatly appreciates the cooperation of J. Angelelli (OR), R. T. Brock (SR), R. Garrison (DOE DP-121), K. Golliher (DOE/AL), J. Leonard (DOE DP-4.1), and H. Stringfield (FBF). Special thanks are due to F. A. Duran (Los Alamos Technical Associates) for her contributions in preparing this report.

91121571212

EXECUTIVE SUMMARY

The Department of Energy (DOE) Container Weld Advisory Committee (CWAC) has concluded its task assigned in Section C of the DP-1.0 Troy Wade memorandum dated January 24, 1989. This memorandum directed DOE Albuquerque Operations (DOE/AL) to convene a working committee of welding and welding inspection experts to make recommendations and provide criteria for specific weld issues related to the Department of Transportation (DOT) 2R inner container.

The charter and scope of the CWAC's activities included three items:

1. Develop recommendations which address the FBF Nuclear Containers manufactured 2R weld issue.
2. Determine inspection, test, and acceptance criteria for the existing DOT specification 6M 2R inner container welds.
3. Determine inspection, test, and acceptance criteria for future inner container welds.

The recommendations and criteria offered by the committee are based on one or more of the following: technical evidence, existing documentation, confirmed statements made during fact finding interviews, or expert opinion. If the information is considered expert opinion only, the statement is so prefaced. This committee was sensitive to budget and schedule considerations; however, the driving force behind their work was to present the technical facts in a straightforward manner and develop appropriate recommendations based on those facts.

Approach and Observations

In addressing Item 1 of the charter and scope, the committee studied the DOT specification for the 2R containers; evaluated the technical correctness of selected purchase order requirements; consulted with DOE

Headquarters (DOE/HQ) to determine the root cause of the issue; and evaluated FBF's compliance with the DOT specification requirements and supplemental specification requirements imposed by purchase orders. The committee reviewed the background for the weld issue and conducted an audit of FBF which included review of many drawings, purchase orders, and related documents.

The committee's review identified evidence of deficiencies in many elements of the DOE community's actions to acquire shipping containers. These included deficiencies in packaging design, packaging procurement specification, vendor qualification audits, manufactured weld controls in the area of procedure qualification and weld performance qualification, process inspection, receiving inspection, quality documentation, and technical direction from DOE/HQ. In the opinion of this committee, the evidence reviewed implies that the DT14-A and 6M 2R packages are not unique in that manufacturing, weld, and material control problems may exist for other fabricators and packagings used for the transportation and storage of radioactive materials within the DOE system.

During the course of the weld review, this committee observed examples of new 2R designs being produced with additional weld and design controls in an attempt to overcome problems recently identified with the DOT specifications. However, some new designs fall short of providing a complete solution and may still present problems due to lack of suitable technical expertise in their conception and execution.

In addressing Items 2 and 3 of the charter and scope, the committee evaluated the 2R inner container design, and reviewed the applicable code requirements and federal regulations to develop its recommendations for inspection, test, and acceptance criteria of existing 2R containers and future inner container designs. The approach for addressing Item 2 (existing containers) included evaluating a baseline 2R design. Then, based on a stress analysis for the baseline design and an evaluation of existing data from other reports, the CWAC developed criteria for a proof test to be performed on existing 2R inner containers. The approach for

addressing Item 3 (future containers) included developing criteria for materials, welding, and quality assurance (QA) that would assure compliance with 10 CFR 71 requirements and other applicable regulations. These criteria are recommended for use in fabricating future inner containers.

Recommendations

For Item 1 of the charter and scope, the committee recommends the following:

1. Qualified individuals should review procurement practices and technical weld requirements before orders are placed for future containers. Further, internal procedures and quality documentation should be audited to assure the containers meet the required specification.
2. DOE should develop uniform criteria from a central point that will provide precise, consistent, and complete direction for container procurement. The criteria should include recommendations such as those presented for Item 3 of the CWAC's charter and scope.
3. FBF should be evaluated on a case-by-case basis for its ability to produce acceptable packaging to meet future DOE procurement specifications.
4. Future considerations of technical issues associated with packaging safety, such as weld criteria, should involve a team of unbiased experts assigned to more clearly identify and evaluate the technical facts immediately after the problem is recognized and before action with far-reaching implications is taken.

For Item 2 of the charter and scope, the committee recommends the following:

1. Each 6M 2R should be tested so that the end plate will be subjected to an outward directed uniaxial static force of 24,400 lb. Appendix B

provides general guidance for conducting the test. Subjecting the 2R weldment to the static force will ensure that the weld is strong enough to withstand the postulated hypothetical accident condition loadings. Acceptance criteria for the force test shall be based on no detectable yielding of the weld. If the container successfully passes the force test, a leak test shall be conducted in accordance with ANSI N14.5 to check for unacceptable leak paths in the weld.

The tests may be conducted at the individual contractor sites. Each site should develop their own test procedures so that the required tests are compatible with existing test hardware and container inventories.

2. If individual 2R inner containers are not permanently marked or do not have a traceable QA file, the container shall be permanently marked and a QA file established.

It is possible that individual field offices may have containers or a specific lot of containers that have a sufficient pedigree to assure quality containers. This would include a traceable QA file on individual containers and analysis and/or testing to demonstrate an adequate level of safety. However, it is the opinion of this committee (formed from evaluation of past procurement practices) that an approved QA procedure does not necessarily result in high quality 2R inner container welds. Therefore, this committee recommends that 100% of all DOE 2R inner containers be tested as indicated above.

3. Paragraph 3(b) of 49 CFR 178.104 excludes the use of cast iron for 2R fabrication. In practice, the end caps which are provided with the 2R are often made out of malleable iron, which is a cast product. Because the end cap is part of the containment vessel, a literal interpretation of the specification would prohibit malleable iron from being used for the end caps. Previous severe accident simulation tests [8, 9] have shown that cast iron caps can shatter upon severe impact. Although this issue is beyond the scope of the charter for the CWAC, it is

9 | 1 | 2 | 3 | 4 | 5 | 6 | 7 | 8 | 9 | 10 | 11 | 12 | 13 | 14 | 15 | 16 | 17

recommended that the Packaging Characteristics Committee (PCC) address the issue. The most definitive solution would be to replace any malleable iron end caps with acceptable material end caps after proof testing.

For Item 3 of the charter and scope, the committee recommends the following:

1. Requirements for materials:

- For double containment, use materials specified in American Society of Mechanical Engineers (ASME) Boiler and Pressure Vessel Code, Section III, NB-2000 and apply fracture toughness criteria defined in Nuclear Regulatory Commission (NRC) NUREG/CR-3019.
- For single containment, use materials specified in ASME Section III, ND-2000 with emphasis on specifying "normalized, fine-grained practice."
- Provide option for using austenitic stainless steel.

2. Requirements for welding program:

- Remove weld joint from high-stress regions where possible.
- Provide workmanship criteria according to ASME Section III, NB-4000 for double containment or to ASME Section III, ND-4000 for single containment.
- Provide inspection criteria according to ASME Section III, NB-5000 for double containment or to ASME Section III, ND-5000 for single containment.
- Full penetration welds located where they can be easily evaluated by nondestructive examination (NDE) techniques.

3. Requirements for quality assurance (QA) program:

- Adhere to QA criteria in 10 CFR 71.

- Adhere to ASME Section III, NCA for material traceability and document control.
- No "N" stamp is required.

The committee offers recommendations specifically for the problems it addressed related to the DOT 2R packaging issue. Recommendations to resolve issues associated with restricted use of DT14-A containers were considered outside the scope of this committee. However, some of the recommendations included in this report may apply to DT14-A containers. The additional task of addressing issues associated with current DT14-A containers may be addressed by the CWAC upon request from the proper authority.

911217.219

CONTENTS

	Page
Acknowledgements	ii
Executive Summary	iii
1.0 Introduction	1
2.0 FBF Manufactured Weld Issue	3
2.1 Background	3
2.2 Approach	3
2.3 Findings	6
2.4 Conclusions	11
2.5 Recommendations	12
3.0 Inspection, Test, and Acceptance Criteria For Existing 2R Inner Container Welds	13
3.1 Background	13
3.2 Approach	13
3.3 Recommendations	22
References	24
4.0 Inspection, Test, and Acceptance Criteria For Future Inner Container Welds	25
4.1 Background	25
4.2 Approach	26
4.3 Recommendations	29
References	32
Appendix A: Stress Analyses of the DOT 2R Inner Container Weldments	A-1
Appendix B: Proposed Weld Integrity Test Characteristics	B-1

911213730

1.0 INTRODUCTION

Section C of the DP-1.0 Troy Wade Memorandum of January 24, 1989 directs the Department of Energy, Albuquerque Operations (DOE/AL) to convene a working committee of welding and welding inspection experts to make recommendations and provide criteria for specific weld issues related to the Department of Transportation (DOT) specification 2R inner container and FBF, Inc. The DOE Container Weld Advisory Committee (CWAC) was established to meet this directive and presents this document as a result of its work.

The membership of the CWAC included technical experts in the fields of welding, weld examination, materials, packaging development, and auditing. The first committee members were selected from a cross-section of the DOE community by nominations from the Packaging Characteristics Committee (PCC). Subsequent members were identified and recruited on the basis of their technical expertise in the fields required to assure credibility of the report contents.

The charter and scope of the committee's activities included three items:

1. Develop recommendations which address the FBF Nuclear Containers manufactured 2R weld issue.
2. Determine inspection, test, and acceptance criteria for the existing DOT specification 6M 2R inner container welds.
3. Determine weld inspection, test, and acceptance criteria for future inner container welds.

Each of the major sections of this report addresses one item of the CWAC's charter and scope, outlining the approach and presenting the findings, if any, and recommendations. The information contained in this report was either obtained through fact finding missions and interviews

with personnel identified as being involved with the associated issues or developed by the independent technical experts on the committee. The fact finding missions included visits to DOE Headquarters (DOE/HQ), DOE/AL, Oak Ridge (OR), Savannah River (SR), and FBF Nuclear Containers, Inc.

The recommendations and criteria offered in this report are based on one or more of the following: technical evidence, existing documentation, confirmed statements made during fact finding interviews, or expert opinion. If the information is considered expert opinion only, the statement is so prefaced. This committee was sensitive to budget and schedule considerations; however, the driving force behind this document was to present the technical facts in a straight forward manner and develop appropriate recommendations based on those facts.

The committee addressed only DOT 2R packaging problems and recommends solutions specifically for those problems. Recommendations to resolve issues associated with restricted use of DT14-A containers were considered outside the scope of this committee. However, some of the recommendations included in this report may apply to DT14-A containers. The additional task of addressing issues associated with current DT14-A containers may be addressed by the CWAC upon request from the proper authority.

2
2
7
1
2
1
1
6

2.0 FBF MANUFACTURED WELD ISSUE

The first item of the CWAC's charter and scope was to develop recommendations which address the FBF (now known as FBF Nuclear Containers) manufactured 2R weld issue.

2.1 Background

The FBF manufactured weld issue originated when three DT14-A inner containers manufactured by FBF were destructively evaluated in July 1988. The events that led to the destructive evaluation of these containers are related to the procurement of 100 DT14-A containers by the SR/Naval Fuels Program through the Y12 Plant at OR. The chronology of these events is presented in Table 1.

The destructive evaluation of the three containers revealed welds which SR deemed to be unacceptable. Subsequently, an Unusual Occurrence Report (UOR) was issued by SR, as directed by DP-4.1. The issuance of the UOR was followed by a directive from DP-4.1 to suspend use of all DT14 and DT14-A containers, regardless of the fabricator. Another directive issued by DP-121 required weld inspections of all containers manufactured by FBF.

2.2 Approach

The approach developed and undertaken by the CWAC to address Item 1 included the following:

1. Review of the DOT specifications for the 2R containers.
2. Evaluation of the technical aspects of purchase order requirements issued for hazardous material packagings.
3. Consultation with DOE/HQ to obtain information about issues related to FBF welds on DT14-A and 2R containers.

TABLE 1

Chronology of Events Leading to the
FBF Manufactured 2R Weld Issue

Event	Date
DOE Certificate of Compliance issued for DT14-A	1/31/84
NRC Certificate issue for DT14-A	10/31/84
Shipping containers evaluated and DT14-A chosen for FMF with 6L as a backup	10/84
DOE, SR, and NRC meet in Silver Springs to discuss additional contents for the DT14-A	12/05/84
New NRC regulation prohibits new DT14-A containers from being built after 8/31/86	1/86
P.O. 93Y-62561V issued by Martin Marietta to FBF for 100 DT14-A containers	2/20/86
P.O. AX0737206 issued by Dupont to Martin Marietta to procure 100 DT14-A containers	2/24/86
SR inspector approves first five DT14-A containers and the Monothane mold	5/07/86
FBF reports that same SR inspector visited the shop and approved the final containers for shipment	5/86
FBF tests the last DT14-A container (60 psi pressure test) for P.O. 93Y-62561V	5/14/86
Final shipment of DT14-A containers received at SR	9/86
Revised SARP for DT14-A container approved by NRC	12/29/86
SARP supplement prepared and submitted to NRC and DOE	7/87
SR performs an audit of the quality documentation record package to determine if requirements of SARP revision are met; audit identified inadequate QA documentation	9/87
DOE certificate issued	11/87
Dupont QA task team formed to resolve quality concerns	3/88

TABLE 1

Chronology of Events Leading to the
 FBF Manufactured 2R Weld Issue
 (concluded)

Event	Date
Dupont performs destructive evaluation of three DT14-A containers in order to resolve questions raised by the SR audit; weld examination reveals defective welds in 2R inner containers; Unusual Occurrence Report issued	7/88
DP-4.1 and DP-121 issue letters that address the weld problem and require action from all users	8/88
Troy Wade issues DOE letter requiring specific actions	1/24/89

4. Evaluation of FBF's compliance with the DOT specification requirements and any additional requirements imposed by purchase orders.
5. Meet with representatives from OR and SR to establish the facts related to FBF welds on DT14-A containers reported to be unacceptable.

Fact finding visits were made to the DOE/HQ offices of DP-4.1 and DP-121 to obtain background into the reported problems. Additional fact finding trips were also taken to SR, where the problem was initially reported, and to OR. In addition, an in-depth audit was performed at FBF in Knoxville, TN to determine its compliance with the DOT specifications and any additional requirements. The CWAC's fact finding and audit activities included review of drawings, purchase orders, and related documents and interviews with individuals associated with the issue.

2.3 Findings

The CWAC audit of FBF resulted in findings and observations that are discussed and summarized in this section of the report.

10
 9
 8
 7
 6
 5
 4
 3
 2
 1
 0

required," with no criteria supplied. In one case the radiograph requirements varied from one drawing to another for the same weld. On one drawing a note says that "A full 1/4 in. fillet is required....," while the drawing symbol clearly shows a full penetration groove weld.

During the audit, the CWAC reviewed documents associated with SR's procurement of 100 DT14-A containers for technical correctness and for FBF compliance with those requirements. Many of the documents reviewed contained inadequate or misleading information for fabrication. As an example, the purchase order for the 100 DT14-A containers in question includes the drawing from the SARP that states, "Welding shall be in accordance with the AWS standard code for arc and gas welding in building construction." Another drawing for the same container says that all welding shall be in accordance with ASME Section IX. The same drawing requires that weld procedure W106 (a Martin Marietta weld procedure used at OR) be used. In order to comply with Section IX the fabricator has to qualify his own weld procedure, and therefore cannot use the W106 weld procedure. However, the W106 weld procedure is specified in the NRC certificate of compliance for this container. Therefore, the container cannot be fabricated by anyone other than OR, who qualified the W106 weld procedure, without violating the certificate of compliance. This is compounded by a very general reference to AWS on the SARP drawing.

Further review of the documents related to FBF's welds on the SR DT14-A containers revealed that in July 1987, when the required inspection criteria and documentation in the SARP for the DT14-A container were amended, SR performed an internal audit of their quality documentation package in order to determine if they were in compliance with the SARP revision. Three DT14-A containers were sectioned in July 1988 by SR in order to resolve internal audit findings of inadequate quality documentation. The CWAC review of the procurement documentation for the three containers revealed that several requirements had not been met. In particular, the purchase order for these containers required weld procedure and operator qualification to the requirements of ASME Section IX. The QA record package included a procedure qualification record for 304 stainless

steel while the containers are manufactured from carbon steel. The welder performance qualification record was several years old, and no record was included for continuing performance within the required period of time to the specified procedure.

The drawing included in the procurement package specified the size of the welds and the weld process. The drawing is referenced in the Certificates of Compliance from FBF (number T2E 117028, revision J) and stated that weld procedure W106 was to be used to perform the weldment. The W106 weld procedure requires that a Gas Tungsten Arc Welding (GTAW) process be used for the welding. Some of the welds inspected by SR were reported to be made with the Shielded Metal Arc Welding (SMAW) process, and during the course of the CWAC audit verbal comments were made which would lead us to believe that much of the welding was indeed done with the SMAW process. In an examination performed in March 1989, SR verified that the SMAW process was used to fabricate these containers. The DT14-A containers and weld specimens were not available for this committee's examination and were reported by SR as lost. However, overhead projections of micrographs of the specimens, without scale or magnification indicated, were provided to the CWAC. The examination of the sections taken from the three containers revealed welds in all three containers that were deemed to be unacceptable by SR. The examination revealed, most notably, undersize welds in the uppermost weld and both lack of fusion and lack of penetration at the root of some welds. A review of corrective action reports generated by FBF indicated that several weld repairs were made as a result of FBF inspections before shipment. The fact that conditions which required correction before shipment were also found after delivery suggests that in-house inspections were not adequate.

Nine other DT14-A containers fabricated by FBF under a separate OR purchase order were destructively evaluated by the Y12 Plant. These nine containers were fabricated by FBF before the lot of 100 procured by SR. Each container was sectioned in four places, which provided 72 micrographs of welds. Of these, 12 welds showed defects of the same nature as did those from SR. During the audit the CWAC found that welding was being

performed with a combination GTAW/SMAW process, but neither a procedure qualification record nor weld procedure specification was available. However, a welder qualification record was present which qualified the welder for the GTAW/SMAW procedure without the procedure qualification record of the weld procedure specification. This qualification was conducted for FBF externally by an independent company.

Additionally, while all arc welding procedure specifications have required amperage inputs, FBF, at the time of the audit, had no means of verifying the amperage inputs and therefore no means of assuring that all the required parameters were met. In one of the FBF corrective action reports in which a weld had to be ground out and replaced, the inspector noted that the amperage was too low and that it was adjusted "two notches." This does not provide assurance that the amperage requirements were met.

During the audit, the only welding code book which could be located at FBF was the 1976 AWS D1.1. It was reported that one of the welders had a copy of ASME Section IX at home. With the changes which are published annually and the periodic addenda publications throughout the year, a company which is fabricating to specific code requirements must have current code requirements readily available. During the audit, purchase orders were reviewed which imposed the requirements of AWS D1.1, 1979 & 1986, AWS D10.9-80, and ASME Section IX. None of these standards were available at FBF at the time of the audit. During the audit, a lack of knowledge about code requirements was apparent. A company who is bidding on, and performing work to various code requirements should have a qualified individual available who can advise them of the various code and referenced specification requirements. A case in point is the W106 weld procedure which was referenced on the OR drawing.

All welding codes require some form of qualification and certification requirements for the inspector. For example, since 1979 AWS D1.1 has provided guidance for certification for AWS inspectors when required by contract documents. While FBF does provide inspections of the welds, including outside inspections by an independent laboratory, no

21107009

qualification requirements were stated for the inspector; other than American Society of Nondestructive Testing (ASNT) for nondestructive examination. Likewise, no certification records for the inspector(s) were evident, other than those for the nondestructive evaluation service provided by the independent laboratory. While this is not intended to imply that the FBF inspector is not capable, it does at the least cause the validity of the inspections performed by FBF to date to be questionable. A new revision of the FBF Quality Assurance Manual was being prepared for issuance at the time of the audit. This revision may correct the problems identified in this report.

A summary of the findings is presented below.

1. Where DOT specification 2R containers were ordered without additional specific requirements provided by the purchaser, the weld fabrication requirements were generally performed to FBF's interpretation of "a workmanlike manner."
2. In cases where the DOE purchaser determined specific details or documentation requirements, FBF did not consistently meet the specified requirements.
3. When specifying weld and inspection criteria in purchasing documents to provide guidance to the vendor, the organizations procuring the containers often provided inconsistent, contradictory, inadequate, or incomplete information.
4. During the course of the assigned weld review, this committee observed examples of new 2R designs being produced with additional weld and design controls in an attempt to overcome problems recently identified with the DOT specifications. However, some new designs still fall short of providing a complete solution and may present new problems due to the lack of suitable technical expertise in their conception and execution.

2.4 Conclusions

For Item 1 of the charter and scope, the CWAC concludes the following:

1. In the opinion of this committee, 2R inner containers cannot be fabricated in "a workmanlike manner," without established weld process controls as part of the welding program. At the time of the CWAC's audit, FBF did not have established and implemented procedures to sufficiently control their welding program. Thus, this committee has concluded that FBF did not consistently fabricate the 2R inner containers in "a workmanlike manner."
2. The committee's review of FBF evaluated the current (March 1989) and past performance of FBF, but cannot accurately predict future performance because FBF may have taken corrective action to meet the requirements of more stringent orders. Recent improvements made by FBF to correct problems identified by past audits demonstrate their willingness to comply when shown deficiencies.
3. In the committee's opinion, the DOE community has frequently provided direction that is incorrect, contradictory, or incomplete. This opinion has been formed through the review by this committee of many documents that were technically incorrect.
4. In most cases, technical requirements established by the purchaser are being imposed by personnel who do not have the technical background required to assure compliance with regulatory requirements.
5. In the committee's opinion, the evidence reviewed implies that FBF DT14-A and 6M 2R packages are not unique in that manufacturing, weld, and material control problems may exist in other fabricators and packagings used for the transportation and storage of radioactive materials within the DOE system.

2.5 Recommendations

The CWAC recommends the following:

1. Qualified individuals should review procurement practices and technical weld requirements before orders are placed for future containers. Further, internal procedures and quality documentation should be audited to assure the containers meet the required specification.
2. DOE should develop uniform criteria from a central point that will provide precise, consistent, and complete direction for container procurement. The criteria should include recommendations such as those presented for Item 3 of the CWAC's charter and scope.
3. FBF or any other fabricator should be evaluated on a case-by-case basis for their ability to produce acceptable packaging to meet future DOE procurement specifications.
4. Future considerations of technical issues associated with packaging safety, such as weld criteria, should involve a team of unbiased experts assigned to more clearly identify and evaluate the technical facts immediately after the problem is recognized and before action with far-reaching implications is taken.

3.0 INSPECTION, TEST, AND ACCEPTANCE CRITERIA FOR EXISTING 2R INNER CONTAINER WELDS

Item 2 of the CWAC's charter and scope was to determine inspection, test, and acceptance criteria for existing 2R inner container welds used in the DOT specification 6M shipping package.

3.1 Background

The DOT Specifications 49 CFR 178.34 and 49 CFR 178.104 [1] provide guidance for fabricating a Type B package. The DOE has procured thousands of 6M 2R containers which were fabricated to these DOT specifications. The specifications allow a wide choice of materials for fabrication and container design. However, the specifications do not provide guidance in weld joint design nor do they provide an acceptance criteria by which to judge the inherent safety of the package.

This section will propose a test program and an acceptance criteria which will demonstrate a level of safety consistent with the requirements of 10 CFR 71 [2] for existing 2R containers. Since Section 2.0 of this report identified the potential existence of marginal welds in existing 2R containers, it becomes necessary to verify the integrity of existing 2R welds. The following discussion will present an approach for evaluating the existing containers based on calculated stresses using closed-form analytical techniques and existing data from referenced reports [3 - 10]. The results of the evaluation will then be used to establish the proposed test program for acceptance of the existing 2R inner container welds.

3.2 Approach

Figure 1 illustrates, in a qualitative sense, the range of 2R container designs that currently exist. A baseline 2R container which meets the DOT specification, as a minimum, is represented in the lower left-hand box of the matrix. Combinations of improvements in fabrication techniques and/or material selection provide for increased quality and safety. Because

2 1 1 2 1 7 2 1

FABRICATION TECHNIQUE	MATERIAL TYPE			
	BASELINE	BETTER	GOOD	BEST
NO WELDS				
INSPECTABLE WELDS				
UNINSPECTABLE WELDS	ACCEPTANCE BY DOT SPEC.			

ENHANCED QUALITY/SAFETY

Figure 1. Qualitative Assessment of 2R Container Integrity by Relating Material Type to Fabrication Techniques

containers exist in the field which correspond to the conditions represented in the lower left-hand box of Figure 1, this evaluation will focus on these types of containers.

Figure 2 presents the logic diagram used in evaluating the 2R container and in developing recommendations for Items 2 and 3. The stress analysis was performed for the baseline 2R design using closed-form mechanics of materials analysis for normal conditions of transport and hypothetical accident conditions.

Although the DOT specification 2R container does not require compliance with the ASME Boiler and Pressure Vessel Code rules and criteria [11], this evaluation will be guided by the ASME criteria when possible and appropriate. The current licensing criteria for certified Type B containers requires using ASME code materials when possible and the NRC Regulatory Guide 7.6 [12] uses an ASME approach in evaluating stresses in cask containment designs.

The integrity of the 2R container will be judged by calculating the stress levels produced in the container by a prescribed set of loading conditions as specified in 10 CFR 71 [2] for normal conditions of transport and hypothetical accident conditions. These calculated stresses can then be related to minimum material strengths for a given material. Ideally, the materials used are included in the ASME Section III, which provides mechanical property values for use in design.

Table 2 lists minimum material property values for several candidate materials. Because the DOT specification does not list specific grades of materials, representative materials are listed. Also included in Table 2 are materials which to our knowledge have been used to fabricate the 2R containers. The list is not all inclusive, but again, the materials are representative. In general, the yield strength for these materials is in the range of 30 to 40 ksi and the ultimate strength ranges from 48 to 75 ksi. In this analysis, the highest stress allowed in a component under normal conditions is related to the yield stress, S_y , while for

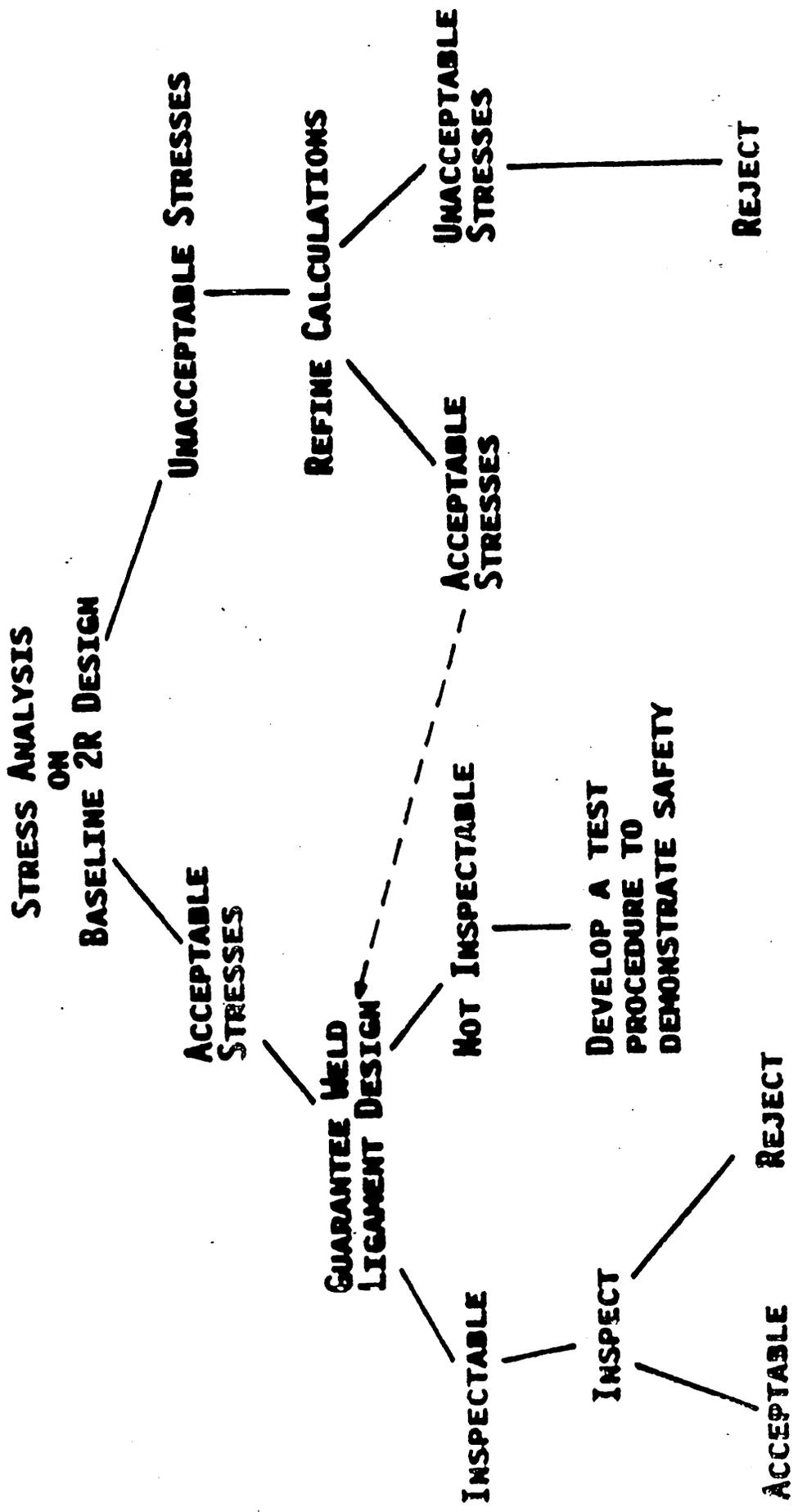


Figure 2. Logic Chart for Defining the Container Assessment Approach

TABLE 2

Minimum Material Properties

Material	Yield Stress (ksi)	Ultimate Stress (ksi)	Elongation (%)
1. DOT Specification			
-- Stainless Steel (SA312 TP304)	30	75	35
-- Malleable Iron (SA47)	32	50	10
-- Brass (SB-43-06)	12	40	--
-- Ferritic Steel (A513-lowest strength grade)	23	38	30
2. Representative Materials Used for the 2R Fabrication			
-- A36	36	58	21
-- A53 Type E			
GR A	30	48	--
GR B	35	60	--
-- A106 GR A	30	48	25
-- GR B	35	60	16 1/2
GR C	40	70	16 1/2
-- A513 Type 5/1026	65	75	10

Notes:

- The DOT 2R specification (49 CFR 178.34) does not provide specification numbers, only general classes of material. The specifications listed in parentheses are examples of suitable materials. The lowest strength grade of A513 is included as a material of "equivalent physical strength" (it has not been identified in any 2R procurement documents).
- The list of material under Item No. 2 is not all inclusive. DOT Specification 49 CFR 178.104 for the 6M prohibits cast iron and brass from being used with a 6M. The materials listed are ferritic steel plate and pipe specifications.

hypothetical accident conditions, maximum allowable stresses are related instead to the ultimate tensile strength, S_u . This follows the philosophy that under normal conditions, the material must never exceed its yield strength. However, in an accident condition, the material may yield, but must not exceed its ultimate tensile strength.

Reference [3] lists a series of drop tests which were conducted on 6M 2R type containers according to the 10 CFR 71 normal conditions of transport. The one normal condition which has not been evaluated is the stress which results from internal gas generation. Therefore, an analysis is provided in this report for normal conditions of transport where stresses are induced in the weld of the 2R inner container due to internal gas generation. Reference [3] presents calculations of internal maximum pressure of 120 psi due to a 10W heat source from the payload in the presence of moisture.

For hypothetical accident conditions, stresses were calculated in the 2R weldment resulting from a 30 ft corner drop loading. Material properties for the internal impact absorber material (Celotex) were obtained from referenced reports (Appendix A.3). To bound the highest stress levels expected from a drop test, the assumptions made in order to perform the analysis were in all cases conservative.

Table 3 lists the results of the calculations. The detailed calculations are provided in Appendix A. The S_y and S_u material property values are related directly to the maximum allowable stresses for the normal transport conditions and the hypothetical accident conditions. These allowable levels are then compared directly with the calculated stress levels. For normal conditions, the bending stress in the weld is secondary and the primary stress is pure shear across the weld throat. A secondary stress is defined as self-limiting. Local yielding can satisfy the conditions which cause the stress to occur. For the case of the 2R weld, the bending stress is secondary as long as the stresses in the end plate remain below yield. This criterion is met for the 120 psi pressure load inside the 2R container. As shown in Table 3, the calculated primary

TABLE 3

Comparison of Stress Allowables to Calculated Stresses (ksi)
in the Container Weld for Selected Materials

Material	Sy	Su	Normal Conditions (120 psi)				Hypothetical Accident Conditions (30 ft. corner drop)	
			0.6 Sy	Primary rmax	Secondary 2 Sy	Smax	0.6 Su	rmax
SA312 TP304	30	75	18	1.2	60	24.9	36	15.1
A36	36	58	21.6	1.2	72	24.9	34.8	15.1
A53 GR A	30	48	18	1.2	60	24.9	28.8	15.1
B	35	60	21	1.2	70	24.9	36	15.1
A106 GR A	30	48	18	1.2	60	24.9	28.8	15.1
B	35	60	21	1.2	70	24.9	36	15.1
C	40	70	24	1.2	80	24.9	36	15.1
A513 (lowest strength)	23	38	13.8	1.2	46	24.9	22.8	15.1
Type 5/1026	65	75	39	1.2	130	24.9	36	15.1

Notes:

1. Sy - yield strength, Su - ultimate tensile strength.
2. 0.6 Sy - maximum allowable pure shear stress.
3. rmax - calculated maximum primary shear stress.
4. 2 Sy - maximum allowable secondary stress.
5. Smax - calculated principal secondary stress in weldment (see Appendix A)
6. 0.6 Su - maximum allowable pure shear stress. If Su > 60 ksi for the parent material, Su - 60 ksi was used to take into account the weld metal minimum strength.

shear stress of 1.2 ksi is significantly below the lowest allowable stress of 13.8 ksi (A513 lowest grade). This represents a factor of safety of 11.5. The secondary stresses are also below the allowable values listed in Table 3.

For the accident condition analysis, the allowable stress requirements are also met. The maximum calculated primary shear stress is 15.1 ksi in the weld. The lowest allowable stress (again for the A513 lowest strength grade) is 22.8 ksi. This represents a 1.5 factor of safety. Consistent with the AMSZ code philosophy, there are no specific limits for secondary stresses for accident condition loadings.

Because of the low calculated primary shear stresses relative to the stress allowables, an undersized weld or sub-quality weld could still withstand the loads imposed on the weldment. However, upon evaluation of the information concerning existing weldments, the issue became one of how much ligament is needed to withstand the calculated normal and accident condition loads. Therefore, an inspection and test procedure is needed to verify a minimum weld ligament.

Weld inspection by destructive examination of a statistically relevant number of containers from a given lot is not included in the recommendations for Item 2. Although this approach was recommended in two DOE/HQ directive letters, the effect of past procurement and operational practices render this approach unsatisfactory. Different fabricators used different materials and weld designs. Further, 2R inner containers are not necessarily permanently marked and are interchanged between 6M packages. Thus, traceability of the 2R does not exist in every case. Any given DOE site may inventory containers from different fabricators using different materials and weld practices. A destructive examination on a limited number of containers would provide an evaluation of those specific containers only. Judging weld integrity for any uninspected containers by extrapolating the conclusions of the inspected containers would be inappropriate. Even if a large percentage of containers (which could be considered truly representative of the entire population at a DOE site)

were sampled, the results would likely yield large uncertainties and would not provide conclusive evidence on which to base a judgement.

Nondestructive weld inspection techniques were also considered so that 100% of the containers could be evaluated. The CWAC concluded that the joint design most commonly used for the existing 2R welds render ultrasonic and radiographic inspection techniques unworkable. The fillet weld and 90 degree joint (see typical weld detail in Appendix A-1) make meaningful inspection very difficult using these two techniques. Surface and near-surface inspection (liquid penetrant and magnetic particle) will provide only part of the story regarding weld integrity. Subsurface volumetric flaws will not be detected using these two techniques.

The use of a drop test to demonstrate safety is not included in this recommendation for the same statistical reason discussed previously. Numerous drop tests have been performed on these types of containers [3 - 10]. Although the 2R containers were uninstrumented in general, the inner container weldments were judged to have successfully passed the drop tests.

It is clear from the preceding arguments that 100% inspection of existing 2R inner containers is required. The committee evaluated the possibility of using a pressure test as a means of inspection. Considering the conditions for the analysis presented in Appendix A, a pressure sufficient to stress the weld to the level of the allowables shown in Table 3 would yield the center of the welded end plate. Therefore, performing a pressure test at a pressure that would not yield the center of the plate would not result in weld stresses which were meaningful. This conclusion is demonstrated in Reference [10] which describes the testing of a 2R container that was pressurized to failure. The pressure at failure was 2700 psi. The middle of the plate showed visible large scale deformation well before failure (which did eventually take place through the weld).

A uniaxial force can be applied to the 2R end plate which equals the calculated dynamic force resulting from the end drop analysis. Appendix A.3 presents the calculations for the required force of 24,400 lb to

produce a stress level of 15.1 ksi (Table 3) in the full-sized weld. A procedure is outlined in Appendix B by which 100% of the 2R containers can be tested using a relatively simple ram apparatus to apply the static force to the end plate. This procedure has the advantage over the pressure test of not subjecting the middle of the end plate to bending. This procedure can be used on all containers, will not yield the end plate material in bending, and will test the weld to a loading equivalent to (or higher than) what would be expected from a 30 ft drop test. Appendix A.4 provides a comparison of calculated stresses resulting from a pressure test and a force test.

A fracture mechanics evaluation was not formally considered in this report. ASME, Section III, NB-2310 does not require fracture toughness testing for material less than 5/8-in. thick. However, the recommended uniaxial force test will inherently provide a test for brittle fracture.

3.3 Recommendations

1. Each 6M 2R with welded end plates should be tested so that the end plate will be subjected to an outward directed uniaxial static force of 24,400 lb. Appendix B provides general guidance for conducting the test. Subjecting the 2R weldment to the static force will ensure that the weld is strong enough to withstand the postulated hypothetical accident condition loadings. Acceptance criteria for the force test shall be based on no detectable yielding in the weld.

A leak test after the force test should be conducted to check for leak paths in the weld. The leak test shall be conducted in accordance with American National Standards Institute (ANSI) N14.5 for leak tests on packages for shipment of radioactive materials. Reference ANSI 14.5 Appendix 3.4, Soap Bubble Test, for the test procedure. The test container shall be pressurized to a test pressure of 14 psig for 15 min. Then, with the container still pressurized, all possible leak areas of the weld will be coated or brushed with a soap solution. The solution must bridge all weld areas to be effective. Bubbling of the solution indicates a leak path in the weld. Any bubbling is cause for

rejection of the container. Commercial soap solutions with low surface tensions are available for use in this leak test. After completion of the testing, the effected area will be cleaned.

The tests may be conducted at the individual contractor sites. Each site should develop their own test procedures so that the required tests are compatible with existing test hardware and container inventories.

2. If individual 2R inner containers are not permanently marked or do not have a traceable QA file, the container shall be permanently marked and a QA file established.

It is possible that individual field offices may have containers or a specific lot of containers that have a sufficient pedigree to assure quality containers. This would include a traceable QA file on individual containers and analysis and/or testing to demonstrate an adequate level of safety. However, it is the opinion of this committee (formed from evaluation of past procurement practices) that an approved QA procedure does not necessarily result in high quality 2R inner container welds. Therefore, this committee recommends that 100% of all DOE 2R inner containers be tested as indicated above.

3. Paragraph 3(b) of 49 CFR 178.104 excludes the use of cast iron for 2R fabrication. In practice, the end caps which are provided with the 2R are often made out of malleable iron, which is a cast product. Because the end cap is part of the containment vessel, a literal interpretation of the specification would prohibit malleable iron from being used for the end caps. Previous severe accident simulation tests [8, 9] have shown that cast iron caps can shatter upon severe impact. Although this issue is beyond the scope of the charter for the CWAC, it is recommended that the PCC address the issue. The most definitive solution would be to replace any malleable iron end caps with acceptable material end caps after proof testing.

1112171217

References

1. "Shipping Container Specifications," Code of Federal Regulations, Transportation, Title 49, Part 178, U.S. Government Printing Office, Washington, DC, October 1987.
2. "Packaging and Transportation of Radioactive Material," Code of Federal Regulations, Energy, Title 10, Part 71, U.S. Government Printing Office, Washington, DC, January 1988.
3. "A Review of the Safety Features of 6M Packages for DOE Programs," SAND88-3005, Sandia National Laboratories, Albuquerque, NM, December 1988.
4. Adcock, F. E., and W. F. Wackler, "RFD Container Model 1518 for Fissile Class II and Class III Shipments," RFP-1042, Dow Chemical Co., Rocky Flats Divisions, 1968.
5. Adcock, F. E., et al., "Rocky Flats Model 2030-1 Container (AEC-AL USA/5332/BLF), Safety Analysis Report for Packaging (SARP), Revision 1," RFP-1867, February 1974.
6. Devore J. R., "Safety Analysis Report for Packaging: The ORNL DOT Specification 6M - Tritium Trap Package," ORNL/TM-8633, Oak Ridge National Laboratories, Oak Ridge, TN, April 1984.
7. Schaich R. W., "Safety Analysis Report for Packaging: The ORNL DOT Specification 6M - Special Form Package," ORNL/TM-8340, Oak Ridge National Laboratories, Oak Ridge, TN, July 1982.
8. McWhirter, M., et al., "Final Report on Special Tests of Plutonium Oxide Shipping Containers to FAA Flight Recorder Survivability Standards," SAND75-0446, Sandia National Laboratories, Albuquerque, NM, September 1975.
9. Bonzon, L. L., "Final Report on Special Impact Tests of Plutonium Shipping Containers, Description of Test Results," SAND76-0437, Sandia National Laboratories, Albuquerque, NM, February 1977.
10. "Weld Integrity of 2R Containers," LXS, 31-88, EG&G Idaho, September 1988.
11. "Rules for Construction of Nuclear Power Plant Components," ASME Boiler and Pressure Vessel Code, Section III, American Society of Mechanical Engineers, New York, NY, July 1986.
12. "Design Criteria for the Structural Analysis of Shipping Cask Containment Vessels," Regulatory Guide 7.6, U.S. Nuclear Regulatory Commission, Washington, DC, March 1978.

4.0 INSPECTION, TEST, AND ACCEPTANCE CRITERIA FOR FUTURE INNER CONTAINER WELDS

The third item in the CWAC's scope and charter is to develop weld inspection, test, and acceptance criteria for future generation containment vessels. During the fact finding audit of FBF Nuclear Containers and in the course of this committee's investigation, it has become evident that guidance for the selection of materials, welding joint designs, and joint placement within the containment vessel is also needed.

4.1 Background

Presently, the fabrication of a 2R inner containment vessel has to meet or exceed the requirements stated in 49 CFR 178 [1]. The welding and materials guidance stated in this regulation is vague. 49 CFR 173.24(c) states that welding shall be performed in "a workmanlike manner" using suitable and appropriate techniques, materials, and equipment. This particular paragraph is subjective and does not mandate what "suitable and appropriate" refer to in terms of service conditions. Without specific guidelines for both the design and fabrication phases, suitable materials and fabrication techniques cannot be chosen.

Both written and verbal communication with DOE/HQ offices DP-4.1 and DP-121, have indicated that future fabrication of Type B shipping containment vessels must satisfy requirements set forth by 10 CFR 71 [2]. Paragraph 119 of this part says that measures shall be established to assure that special processes, including welding, heat treating, and nondestructive testing, are controlled and accomplished by qualified personnel using qualified procedures in accordance with applicable codes, standards, specifications, criteria, and other special requirements.

The following discussion presents an approach and recommendations for the fabrication of future inner containment vessels which is consistent with the requirements stated in 10 CFR 71 and NRC published guidelines [3, 4]. It should be noted that these recommendations are not a substitute for

requirements stated in existing containment vessel safety analysis reports, although in many instances these recommendations meet those stated requirements. New containment vessel designs should consider these recommendations when developing safety analysis reports to support containment vessel certification.

4.2 Approach

Good engineering design depends on the sum of many interdependent parts. Arrival at a final design that is manufacturable, cost efficient and suitable for service requires thoughtful consideration of materials used, fabrication and inspection techniques, available manufacturing resources, service conditions, and cost.

All of these factors impact upon each other to a greater or lesser extent. For example, an elevated fracture toughness will impact nondestructive testing requirements in that a less sensitive flaw inspection process will be required simply because the material can tolerate larger flaws. Another impact here will be that, because a more sophisticated material is used, more highly skilled welders will be required. Thus, the lack of specified requirements for or inadequate control within any part of the design and manufacturing sequence may result in unsuitable components.

In order to ensure the quality of welded components, the fabrication sequence must be controlled in all aspects. These parts of the fabrication sequence were broken down as follows:

- Base materials (includes strength and toughness requirements)
- Weld materials (includes strength and toughness requirements)
- Joint preparation and placement
- Welding
- Heat treatment (includes preheat requirements)
- Qualification of procedures and personnel

- Examination
- Quality assurance (refers to administrative procedures rather than technical issues)

The NRC has published guidelines, NUREG/CR-3019, for containment related welds associated with the inner shipping container [3]. This NUREG primarily references the ASME Boiler and Pressure Vessel Code [5] for fabrication requirements. The ASME code was selected because it, historically, has been a proven code in the fabrication of nuclear components. Although the referenced code does not apply directly to the fabrication of shipping containment vessels, it does cover all of the necessary procedure steps to fabricate quality components and can be applied to the fabrication of shipping containment vessels. It should be noted that design criteria which differ from those inherent in the ASME code must be integrated with the design at an early stage in the fabrication sequence before effective control of containment vessel fabrication can be established and maintained.

NUREG/CR-3019 [3] recommends that requirements of NUREG/CR-1815 [4] be used to establish ferritic steel fracture toughness requirements. Three categories are established that provide degrees of safety appropriate to the various materials transported in the containment vessels. An explanation of each category is as follows:

1. Category I gives the largest margin of safety by requiring sufficient toughness to assure that there is no crack propagation at the lowest service temperature. Steel having this level of safety can tolerate large flaws under dynamic loading conditions and its toughness is sufficient to arrest large cracks (i.e., yielding will precede fracture). Materials which typify this category include austenitic stainless steel and "heat treated (normalized) - made to fine grain practice" ferritic steels used on their upper shelf. This behavior is always verified by fracture toughness testing.

- 1112157213
2. Category II provides a smaller margin of safety than does Category I. The minimum level of toughness at the lowest service temperature is specified at a level somewhat above the toughness at the plane strain limit for dynamic loading conditions. If a shock mitigating system, such as an overpack, is effective in reducing the loading rate in the fracture critical components, then an intermediate loading rate can be assumed and an additional reduction in the minimum toughness could be permitted. This criteria is sufficient to prevent fracture initiation of pre-existing cracks under dynamic loading. This category epitomizes the fracture mechanics school of design, where service use is quantified by analysis. Material testing is not mandated for thicknesses less than 0.625 in., hence assumptions relating to materials toughness are implied.
 3. Category III offers a smaller margin of safety than does Category II and the minimum corresponding fracture toughness is also reduced. Good engineering practices and selection of steels with low nil ductility temperatures make it unlikely that brittle fracture will occur, rather than extensive analysis and testing. Note that this approach while having lower toughness stipulations may actually require a more conservative (i.e., better) materials choice. This level of toughness will only tolerate small flaws characteristic of good fabrication practices.

Based on the above criteria the following categories were chosen for Type B containment vessel fabrication:

1. Category I fracture toughness criteria were selected for components shipped in accordance with the requirements of 10 CFR 71.63 (e.g., double containment).
2. Category II fracture toughness criteria were selected for containment vessels which transport all other types of contents. This approach takes credit for use of the shock mitigating overpack, which reduces the dynamic fracture toughness requirements.

Category III fracture toughness criteria were not chosen because critical flaw sizes may be smaller than inherent notches typical of commercial fabrication practices.

4.3 Recommendations

The following recommendations are for materials with a thickness between 0.019 in. and 0.625 in. and yield strengths less than or equal to 100 ksi:

1. The selection of base materials shall be limited to the materials included in ASME Section III, NB-2000. The weldability of these materials are classified by a P number designation in Section IX. Materials not included in Section IX are acceptable providing the weldability of such materials are classified by P number or S number in accordance with applicable requirements stated in NUREG/CR-1815. Category I fracture toughness criteria shall be applied to material used in fabrication of ferritic Type B packaging, the contents of which require shipment in accordance with the requirements of 10 CFR 71.63 (e.g., double containment). Category II fracture toughness criteria shall be applied to materials used in fabrication of all other ferritic Type B packaging. The option of using normalized steels made to fine grained practice shall be used to satisfy this fracture toughness criteria. Materials made to, but not limited to ASME Section II, SA-320, SA-333, SA-334, SA-420, and SA-516 satisfy this condition. It should be reemphasized that all types, grades, or classes within these subsections do not necessarily meet the "normalized made to fine grain practice" criteria, thus particular attention should be given to material purchasing requirements. Use of austenitic stainless steels, such as those included in ASME Section II, SA-240, SA-312, and SA-403 can be considered as an alternative approach to fracture toughness characterization of ferritic steels for Category I and Category II.
2. Weld materials used to fabricate containment vessels where Category I fracture criteria is applied shall meet the requirements of ASME

Section III, NB-2400. Welding and filler metal identification and control shall meet the requirements specified in ASME Section III, NB-2150. Comparable paragraphs from ASME Section III, ND shall be used for containment vessel fabrication where Category II fracture toughness is applied.

3. Weld joint preparation where Category I fracture criteria is applied shall meet the requirements of ASME Section III, NB-4200. The welds shall be full penetration joints and be placed remote from high stress locations, whenever possible. This entails use of Category B circumferential butt welds as specified in ASME Section III, NB-3351.2. Comparable paragraphs from Subsection ND shall be used for containment vessel fabrication where Category II fracture toughness is applied. Joint placement shall specifically consider the nondestructive examination requirements.
4. Welding on containment vessels where Category I fracture criteria is applied shall be performed in accordance with the workmanship criteria specified in ASME Section III, NB-4000. Comparable paragraphs from Section III, ND shall be used for containment vessel fabrication where Category II fracture toughness is applied.
5. Heat treatment on containment vessels shall be used where Category I fracture requirements of ASME Section III, NB-4600 apply, except where it can be shown (by qualification) that the deletion of the post weld heat treatment will result in equal or improved flaw tolerance properties. Comparable paragraphs from Section III, ND shall be used for containment vessel fabrication where Category II fracture toughness is applied.
6. Qualification of welding procedures and personnel used in fabricating containment vessels where Category I fracture criteria is applied shall be in accordance with the requirements of ASME Section III, NB-4300. Comparable paragraphs from Section III, ND shall be used for containment vessel fabrication where Category II fracture toughness is

applied. See paragraph 9 for additional nondestructive examination requirements.

7. Examination of containment vessels where Category I fracture criteria is applied shall be in accordance with the requirements of ASME Section III, NB-5000. Comparable paragraphs from Section III, ND shall be used for containment vessel fabrication where Category II fracture toughness is applied.
8. A quality assurance program shall be established and applied to the entire design, procurement, and manufacturing process. It shall meet the requirements specified in Subpart H in 10 CFR 71. The quality assurance program shall be used to establish appropriate controls of material traceability and document control covered in ASME Section III, NCA.
9. Fracture toughness of the weld metal and heat affected zone shall meet or exceed the minimum requirements of the base material. Actual fracture toughness test data from the weld procedure qualification test (or a successful welder certification test to that specific procedure) shall be used to demonstrate this compliance. The supplementary requirements for notch toughness specified in ASME Section IX shall be applied during qualification of the weld procedure. Welding procedure specifications used for welding production containment vessels shall contain sufficient detail to control these requirements during fabrication.

When the optional full-scale drop test, described in NUREG/CR-1815 is used for demonstrating toughness, the supplementary requirements for notch toughness specified in the ASME Section IX shall be applied during qualification of the welding procedure. Welding procedure specifications used for welding production containment vessels shall contain sufficient details to control these requirements during fabrication.

References

1. "Shipping Container Specifications," Code of Federal Regulations, Transportation, Title 49, Part 178, U.S. Government Printing Office, Washington, DC, October 1987.
2. "Packaging and Transportation of Radioactive Material," Code of Federal Regulations, Energy, Title 10, Part 71, U.S. Government Printing Office, Washington, DC, January 1988.
3. Monroe, R. E., H. H. Woo, and R. G. Sears, "Recommended Welding Criteria For Use in the Fabrication of Shipping Containers for Radioactive Materials," NUREG/CR-3019, Lawrence Livermore National Laboratory, Livermore, CA, March 1985.
4. Holman, W. R., and R. T. Langland, "Recommendations for Protecting Against Failure by Brittle Fracture in Ferritic Steel Shipping Containers Up to Four Inches Thick," NUREG/CR-1815, Lawrence Livermore National Laboratory, Livermore, CA, August 1981.
5. "Rules for Construction of Nuclear Power Plant Components," ASME Boiler and Pressure Vessel Code, Section III, American Society of Mechanical Engineers, New York, NY, July 1986.

APPENDIX A

STRESS ANALYSES OF THE DOT 2R INNER CONTAINER WELDMENTS

- A.1 2R Geometry
- A.2 Normal Conditions of Transport
- A.3 Hypothetical Accident Condition
- A.4 Comparison of Calculated Stresses
Resulting from a Pressure Test and
A Force Test

112157223

A.1 2R GEOMETRY

The basic geometry is defined in 49 CFR 178.34 with the 6M specification
49 CFR 178.104 further restricting the 2R to:

Inner diameter = 4 in. to 5.25 in.

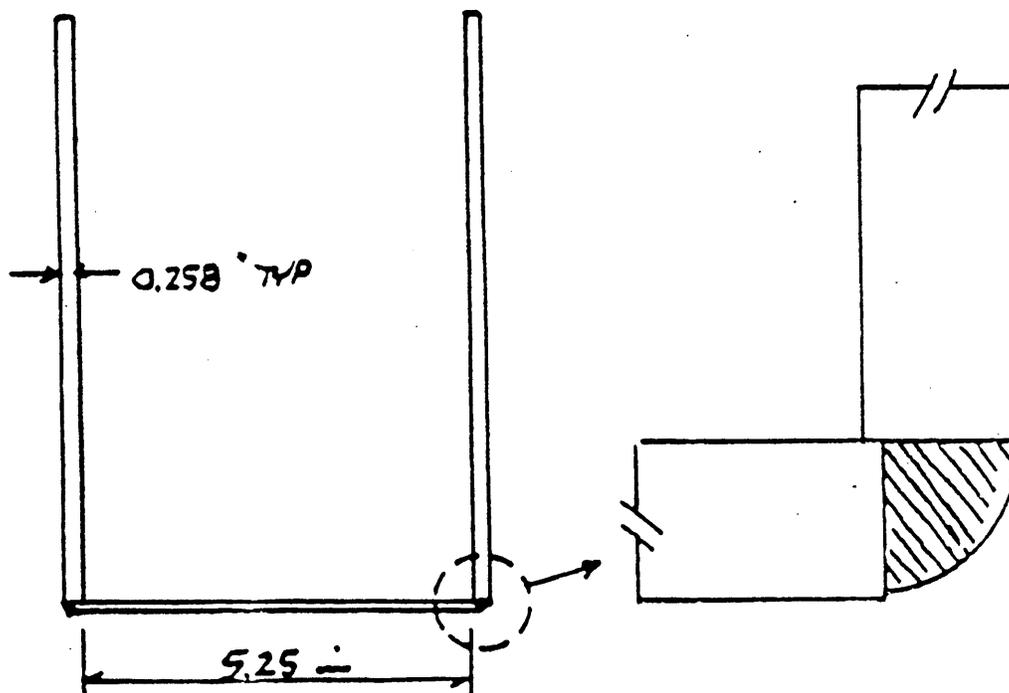
Minimum height = 6 in.

Schedule 40 pipe equivalent wall thickness

For this analysis:

Inner diameter = 5.25 in.

Wall thickness, $t = 0.258$ in.



Typical Weld Detail

Step 2. Calculate the Influence Coefficients

A. Element A (Cylinder)

W - Radial displacement

θ - Rotation

$$W_{AC} = (\beta_{11}/2\beta^3 D)Q_c + (\beta_{12}/2\beta^2 D)M_c$$

$$\theta_{AC} = (\beta_{12}/2\beta^2 D)Q_c + (\beta_{22}/\beta D)M_c$$

Evaluate the constants (Article A-2120)

$$\beta = \left\{ \frac{3(1 - \nu^2)}{(R + t/2)^2 t^2} \right\}^{1/4} = \left\{ \frac{3(1 - 0.3^2)}{[2.625 + (0.258/2)]^2 (0.258)^2} \right\}^{1/4}$$

$$\beta = 1.5249 \text{ in.}^{-1}$$

$$D = \frac{Et^3}{12(1 - \nu^2)} = \frac{29(10)^6 (0.258)^3}{12(0.91)}$$

$$D = 45607 \text{ in.} \cdot \text{lb}$$

$$\beta_{11} = 1, \beta_{12} = 1, \beta_{22} = 1$$

$$\therefore W_{AC} = [3.0918Q_c + 4.7147M_c] 10^{-6}$$

$$\theta_{AC} = [4.7147Q_c + 14.379M_c] 10^{-6}$$

B. Element B (Circular Flat Plate)

$$W_{BC} = \frac{-2F_3}{3E(t/R)} Q_c + \frac{F_3}{ER(t/R)^2} M_c$$

$$\left. \begin{array}{l} \text{For } t/R = 0.258/2.754 = 0.0937 \\ F_3 = 3.875 \end{array} \right\} \text{Table A-5240-1}$$

$$\theta_{BC} = \frac{F_3}{ER(t/R)^2} Q_c - \frac{2F_3}{ER^2(t/R)^3} M_c$$

$$W_{BC} = \frac{-2(3.875)}{3(29)(10)^6(0.0937)} Q_c + \frac{3.875}{29(10)^6(2.754)(0.0937)^2} M_c$$

112157226

$$\theta_{BC} = \frac{3.875}{29(10)^6 (2.754)(0.0937)^2} Q_c - \frac{2(3.875)}{29(10)^6 (2.754)^2 (0.0937)^3} M_c$$

$$W_{BC} = [-0.9507Q_c + 5.5263M_c] 10^{-6}$$

$$\theta_{BC} = [5.5263Q_c - 42.831M_c] 10^{-6}$$

Step 3: Calculate the Edge Deformations Due to the Internal Pressure

A. Element A

$$W_{AC} = [1 - (\nu/2)] (\rho R R_m / E t)$$

$$= [1 - 0.15] (120(2.625)(2.754) / 29(10)^6 (0.258))$$

$$W_{AC} = 98.554(10)^{-6}$$

$$\theta_{AC} = 0$$

B. Element B

$$\theta_{BC} = \frac{F_1}{E(\epsilon/R)^3} \rho$$

$$\left. \begin{array}{l} \text{For } \epsilon/R = 0.0937 \\ F_1 = 0.8721 \end{array} \right\} \text{Table A-5240-1}$$

$$\theta_{BC} = \frac{0.8721(120)}{29(10)^6 (0.0937)^3}$$

$$\theta_{BC} = 4386.63(10)^{-6}$$

$$W_{BC} = -\frac{\epsilon}{2} \theta = -\frac{0.258}{2} (4386.63)(10)^{-6}$$

$$W_{BC} = -565.88(10)^{-6}$$

Step 4. Thermal Forces - N/A

Step 5. Equate the Total Lateral Displacements and Rotations

$$W_{AC} = W_{BC}$$

$$[3.0918Q_c + 4.7147M_c + 98.554]10^{-6}$$

$$= [-0.9507Q_c + 5.5263M_c - 565.88]10^6$$

$$\theta_{AC} = \theta_{BC}$$

$$[4.7147Q_c + 14.379M_c]10^{-6}$$

$$= [5.5263Q_c - 42.8309M_c + 4386.63]10^{-6}$$

Now, combine like terms and multiply through by 10^6

$$4.0425Q_c - 0.8116M_c = -664.434$$

$$-0.8116Q_c + 57.2099M_c = 4386.63$$

Step 6. Solve the Simultaneous Equations

$$4.0425Q_c - 0.8116M_c = -664.434(x.8116)$$

$$-0.8116Q_c + 57.2099M_c = 4386.63(x4.0425)$$

$$3.2809Q_c - 0.6587M_c = -539.26$$

$$-3.2809Q_c + 231.27M_c = 17,733$$

$$230.61M_c = 17,194$$

$$M_c = 74.56 \text{ in.} \cdot \#/\text{in.}$$

$$-3.2809Q_c + 231.27(74.56) = 17,733$$

$$-3.2809Q_c = 489.51$$

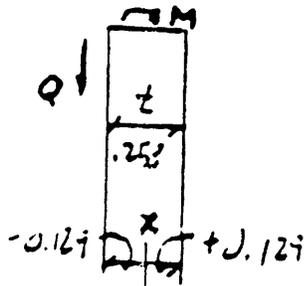
$Q_c = -149.20 \#/\text{in.}$ (The negative value indicates that the actual direction is opposite to that originally chosen.)

Step 7. Compute Maximum Stresses in the Weld joint of the Flat Plate Resulting from the Uniformly Applied Radial Force, Q and Moment, M. Using A-5224-3:

$$\sigma_r = \sigma_c = \frac{-F_4}{t} \left[1 - \frac{6(x)}{t} \right] Q - \frac{12F_4(x)}{t^3} M$$

$$\left. \begin{array}{l} \text{For } t/R = 0.258/2.754 = 0.0937 \\ F_4 = 0.9679 \end{array} \right\} \text{Table A-5240-1}$$

(x) is defined in the flat plate as:



Compute σ for 3 values of (x)
 $x = -0.129, 0, +0.129$

$$\sigma_r(x) = \frac{-0.9679}{0.258} \left[1 - \frac{6(x)}{0.258} \right] (-149.34) - \left[\frac{12(0.9679)(x)}{(0.258)^3} \right] 74.56$$

$$\sigma_r(-0.129) = 8746 \text{ psi}$$

$$\sigma(0) = 560 \text{ psi}$$

$$\sigma_r(+0.129) = -7626 \text{ psi}$$

Compute shear stress in the axial direction from the reactive force, RF

$$\tau_{RF} = \frac{P}{A} \text{ (approximate)}$$

$$P = 120 \text{ #/in.}^2 \left\{ \frac{\pi(5.508)^2}{4} \right\} = 2859 \text{ #}$$

$$A = Ct = \pi(5.508)(0.258) = 4.464 \text{ in.}^2$$

$$\tau_{RF} = \frac{2859}{4.464} = 640 \text{ psi}$$

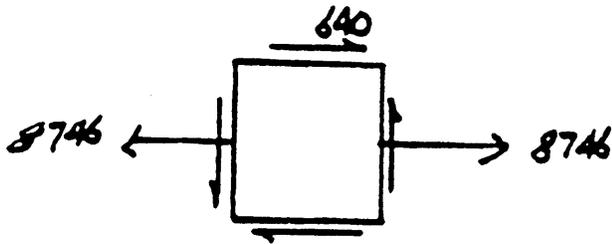
Finally,

$$\sigma_r = \sigma_c = 8746 \text{ psi (max)}$$

$$\tau_{RF} = 640 \text{ psi}$$

Note: Stresses due to pressure are not calculated at the plate boundary (A-5224).

Step 8. Compute the Maximum Principal Stresses



$$\sigma_1 = \frac{8746}{2} + \sqrt{\left(\frac{8746}{2}\right)^2 + (640)^2} = 8793$$

$$\sigma_2 = \sigma_c = 8746 \text{ psi}$$

$$\sigma_3 = \frac{8746}{2} - \sqrt{\left(\frac{8746}{2}\right)^2 + (640)^2} = -47$$

Step 9: Compute Stress Intensities

$$S_{12} = |\sigma_1 - \sigma_2| \qquad S_{12} = 47 \text{ psi}$$

$$S_{23} = |\sigma_2 - \sigma_3| \qquad S_{23} = 8793 \text{ psi}$$

$$S_{31} = |\sigma_3 - \sigma_1| \qquad S_{31} = 8840 \text{ psi}$$

$$\therefore S = 8840 \text{ psi}$$

Step 7. Compute Maximum Discontinuity Stresses in the Weldment of the Cylinder Resulting From the Uniformly Applied Radial Force, Q and Moment M .

$$\sigma_M = \pm \frac{6M}{t^2}$$

$$\sigma_c = \frac{EW}{(R + t/2)} \pm \frac{6 \cdot M}{t^2}$$

$$\sigma_r = 0$$

$$W = (3.0918Q + 4.7147M)10^{-6}$$

$$= (3.0918(-149.34) + 4.7147(74.56))10^{-6}$$

$$- 1.102(10)^{-4} \text{ in.}$$

$$EW = .3196 \text{ #/in.}$$

$$M = 74.56 \text{ in.-#/in.}$$

1. Inside Surface

$$\sigma_M = \frac{6(74.56)}{(0.258)^2} = 6721 \text{ psi}$$

$$\sigma_c = \frac{-3196}{2.625 + 0.129} + \frac{6(0.3)(74.56)}{(0.258)^2} = 856$$

$$\sigma_r = 0$$

2. Outside Surface

$$\sigma_M = \frac{-6(74.56)}{(0.258)^2} = -6721 \text{ psi}$$

$$\sigma_c = \frac{-3196}{2.625 + 0.129} - \frac{6(0.3)(74.56)}{(0.258)^2} = -3177 \text{ psi}$$

$$\sigma_r = 0$$

Step 8. Compute the Stresses Resulting From Internal Pressure

From A-2212

$$\sigma_M = \frac{P}{(Y^2 - 1)}$$

$$Y = 1.0983, Y^2 = 1.2062$$

$$(Y^2 - 1) = 0.2062$$

$$\sigma_c = \frac{P(1 + Z^2)}{(Y^2 - 1)}$$

$$Z = 1.0468, Z^2 = 1.0958$$

$$\sigma_r = \frac{P(1 - Z^2)}{(Y^2 - 1)}$$

$$(1 + Z^2) = 2.0958$$

$$(1 - Z^2) = -0.0958$$

1. Inside Surface ($Z = 1.0983, Z^2 = 1.2062$)

$$\sigma_M = \frac{120}{0.2062} = 582 \text{ psi}$$

$$\sigma_c = \frac{120(2.2062)}{0.2062} = 1284 \text{ psi}$$

$$\sigma_r = \frac{120(-0.2062)}{0.2062} = -120 \text{ psi}$$

Therefore, total stresses are:

$$\sigma_M = 6721 + 582 = 7303 \text{ psi}$$

$$\sigma_t = 856 + 1284 = 2140 \text{ psi}$$

$$\sigma_r = 0 - 120 = -120$$

2. Outside Surface

$$\sigma_M = 582 \text{ psi}$$

$$\sigma_t = 1164 \text{ psi}$$

$$\sigma_r = 0 \text{ psi}$$

Therefore, the total stresses are:

$$\sigma_M = -6721 + 582 = -6139 \text{ psi}$$

$$\sigma_t = -3177 + 1164 = -2013 \text{ psi}$$

$$\sigma_r = 0$$

Step 9. Compute Stress Intensities

$$\sigma_1 = \sigma_M = 7303$$

$$\sigma_2 = \sigma_t = 2140$$

$$\sigma_3 = \sigma_r = -120$$

$$S_{12} = |\sigma_1 - \sigma_2|$$

$$S_{12} = 5163 \text{ psi}$$

$$S_{23} = |\sigma_2 - \sigma_3|$$

$$S_{23} = 2260 \text{ psi}$$

$$S_{31} = |\sigma_3 - \sigma_1|$$

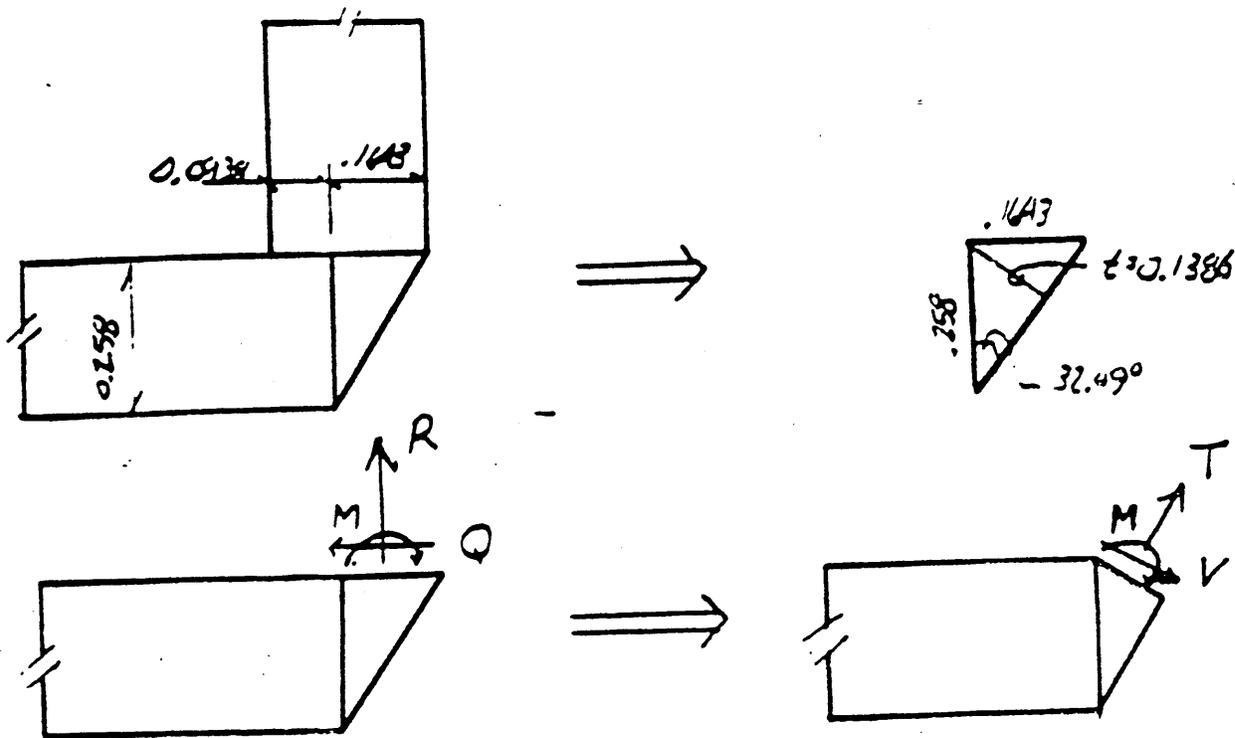
$$S_{31} = 7423 \text{ psi}$$

$$\therefore S_{MAX} = 7423$$

Final Results:

1. Flat Plate: $S_{MAX} = 8840 \text{ psi}$ (Inside Surface)
2. Cylinder: $S_{MAX} = 7423 \text{ psi}$ (Inside Surface)

Step 10. Adjust Stresses to Account for Reduced Throat Dimension of the Fillet Weld



$$R = 120 \left\{ \frac{\pi(5.508)^2}{4} \right\} (\pi 5.508) \cdot 1 = 165.2 \text{ #/in.}$$

$$Q = -149.34 \text{ #/in.}$$

$$M = 74.56 \text{ in. #/in.}$$

$$V = -Q \cos 32.49^\circ - R \sin 32.49^\circ = 37.21 \text{ #/in.}$$

$$T = R \cos 32.49^\circ - Q \sin 32.49^\circ = 219.6 \text{ #/in.}$$

Finally;

$$\begin{aligned} r_{\text{MAX}} &= \sqrt{\left\{ \frac{1}{2} \left(\frac{6M}{e^2} + \frac{T}{e} \right) \right\}^2 + \left(\frac{V}{e} \right)^2} \\ &= \sqrt{\left\{ \frac{1}{2} \left(\frac{6(74.56)}{(0.1386)^2} + \frac{219.6}{0.1386} \right) \right\}^2 + \left\{ \frac{37.21}{0.3186} \right\}^2} = 12,439 \end{aligned}$$

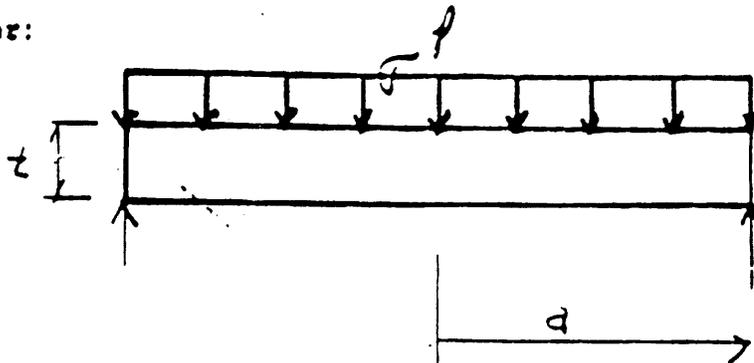
$$S_{\text{MAX}} = 2 \times r_{\text{MAX}} = 2 \times 12,440 = 24,880 \text{ (See Table 3) (ASME NB-3227.2)}$$

1131572203

Step 11. Evaluate Secondary Stresses

A very small weld would not be expected to resist the applied moment. Allowing end rotation reduces the end plate boundary conditions to simply supported with no moment resistance. If the end plate stresses remain elastic, the stresses resulting from the moment force, M, and shear force, Q, become secondary. The remaining primary stress is the shear stress resulting from the longitudinal force, R. (See Table NB-3217-1).

Consider:



$$t = 0.258''$$

$$d = 2.754''$$

$$\nu = 0.3$$

$$p = 120 \text{ psi}$$

$$\sigma_{\text{center}} = \frac{6pa^2(3 + \nu)}{16t^2} = \frac{6(120)(2.574)^2(3 + 0.3)}{16(0.258)^2}$$

$$\sigma_{\text{center}} = 14,780 \text{ psi} \ll \text{Yield stress for any material shown in Table 2 (excluding brass)}$$

∴ Stresses resulting for M and Q forces are secondary

Step 12. Calculate the Primary Stress in the Weld

The primary stress is merely the resultant force, R, divided by the weld throat area.

$$R = 120 \text{ #/in.}^2 \left[\frac{\pi(5.508)^2}{4} \right] = 2859 \text{ #}$$

$$\text{Weld throat area} = 0.1386 (5.508) \times 1 = 2.398 \text{ in.}^2$$

$$\tau_{\text{MAX}} = \frac{2859 \text{ #}}{2.398 \text{ in.}^2} = 1192 \text{ psi (See Table 3)}$$

APPENDIX A.3 HYPOTHETICAL ACCIDENT CONDITION

Evaluation of 2R container end plate weld for 30-foot hypothetical accident condition drop.

1. Determine the maximum acceleration load on the overall 6M/2R system as the result of a 30-foot drop. The maximum acceleration corresponds to a bottom end drop since this orientation immediately mobilizes a large area of Celotex. To obtain a maximum "g" load, the full diameter of the 6M container will be assumed to be effective. Additionally, the compressive crush strength of the Celotex will be taken at 1.5 times the stated compressive strength of 91 psi (provided in Celotex Corporation Technical Bulletin Number 6003, August 26, 1963). The 1.5 factor is used to account for uncertainties in Celotex properties. The maximum end drop force acting on the 6M/2R system, F, therefore becomes:

$$F = 1.5 \sigma_c A$$

where

$$\sigma_c = 91 \text{ psi}$$

$$A = \text{end area of 6M container} = (\pi/4)(d)^2, \text{ in.}^2$$

$$d = \text{diameter of 6M container, in.}$$

Resultant "g" load becomes: $g = F/w$

where

$$w = \text{weight of the loaded 6M/2R system, lb}$$

The following table presents the resultant "g" loads for each size of 6M container.

TABLE A.3-1

Resultant "g" Loads for 6M Containers

Container size (gallons)	Diameter, d (in.)	Empty 6M with empty 2R weight (lb)	Assumed maximum 2R contents weight (lb)	Loaded		6M/2R system weight, w (lb)	Impact force, F (lb)	6M/2R system "g" load
				6M/2R system weight, w (lb)	Impact force, F (lb)			
10	13.9	55	75	130	20,710	159		
30	18.3	125	100	225	35,900	160		
55	22.6	200	100	500	54,760	183		

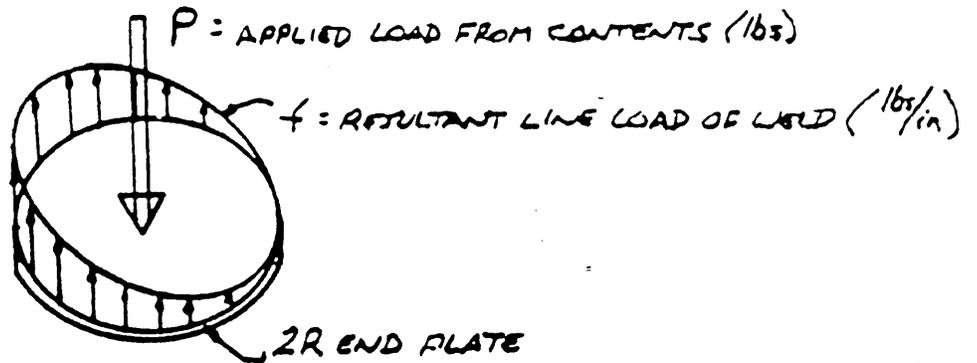
2. Determine the maximum force acting on the 2R end plate. The maximum force acting on the 2R container end plate is taken as the above determined system "g" load times the weight of the contents within the 2R container. This approach conservatively ignores any beneficial force on the end plate associated with the end plate driving into the Celotex and also ignores any beneficial effects associated with the contents themselves absorbing energy. For the particular case of double containment shipments, a variety of energy absorbing components are included as part of the 2R contents (e.g., empty slip lid cans). Again, these are conservatively ignored. The resultant load, P, on the 2R end plate as a function of 6M container size is presented in the following table.

Container Size (gallons)	Maximum 2R contents weight (lb)	"g" load (from 1, above)	Load, P on 2R end plate (lb)
10	75	159	11,930
30	100	160	16,000
55	100	183	18,300

3. Determine stress in 2R container end plate weld. The maximum force on an end plate has been determined to be 18,300 lb. Using a weld throat thickness, t, of 0.123 in. (based on wall thickness of a schedule 40 pipe with an inside diameter of 4 in.) and a minimum inside diameter for a 2R container of 4.0 in. (end plate diameter of 4.188) results in a uniform weld shear stress, τ_{weld} , of:

$$\begin{aligned} \tau_{weld} &= P/A = 18,300/\pi(4.188)(0.123) \\ &= 11,300 \text{ psi} \end{aligned}$$

To account for the fact that in drop orientations such as c.g. over corner the load on the weld may not be uniform around the circumference, the above determined weld shear stress will be multiplied by a factor of 1.333. This factor corresponds to a linearly varying weld stress across the diameter of the end plate as shown below.



The maximum weld shear stress is therefore:

$$r_{MAX} = 1.333(11,300) = 15,060 \text{ psi} \quad (\text{See Table 3})$$

This is well within the ultimate shear capability of the weld which can be taken as 60% of the lower of the minimum ultimate tensile strength of the base metal or weld material, or $0.60(48,000) = 28,800 \text{ psi}$ (for A106 or A53, Gr A material).

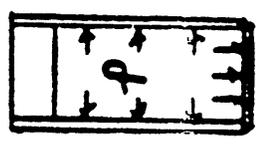
4. Determine the minimum weld throat size required to withstand the 30 foot free drop accident event. The minimum throat size required is simply determined by appropriately ratioing the results available from Step 3 above.

$$\begin{aligned} c_{MIN} &= (r_{MAX}/r_{allow})(c) \\ &= (15,060/28,800)(0.123) \\ &= 0.064 \text{ in.} \end{aligned}$$

5. Determine the end load which results in a uniform weld stress of 13,330 psi (i.e., the highest calculated stress resulting from the 30-foot drop). This end load is simply 1.333 times the maximum load on the end plate determined in Step 2 above, or $1.333(18,300) = 24,400 \text{ lb.}$

APPENDIX A.4

Comparison of Calculated Stresses Resulting From a Pressure Test and a Force Test



Pressure Test

*Calculate a pressure, p, which will produce stresses in the weld comparable to the calculated stress from the 30-ft. drop.

$$r_{max} = 15.1 \text{ ksi (Table 3)}$$

1. Compute p, which yields the plate center:

$$p = \frac{8 \cdot \sigma_{ys} \cdot t^2}{3a^2 (3 + \nu)} = \frac{8 (23,000) (.237)^2}{3 (2.094)^2 (3 + 0.3)}$$

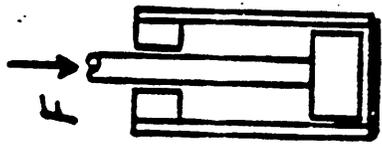
$$p = 238 \text{ psi}$$

$$r_{weld} = \frac{p A_{plate}}{A_{weld}} = \frac{237 (4.188)}{4 (.123)} = 2026 \ll 15,100 \text{ psi}$$

2. Compute p, which yields the weld:

$$p = \frac{r_{ys} A_{weld}}{A_{plate}} = \frac{13,800 (4) (.123)}{4.188} = 1621 \text{ psi}$$

∴ The pressure required to cause yielding in the weld is 6.8 times greater than that required to cause yielding in the plate.



Force Test

*Calculate a force which will result in a weld stress of approximately $r_{max} = 15.1 \text{ ksi}$ (Table 3)

$$F = r_{weld} A_{weld}$$

$$F = 15,100 (\text{wdt})$$

$$F = 15,100 (\pi) (4.188) (.123)$$

$$F_{plate} = 0$$

APPENDIX B

PROPOSED WELD INTEGRITY TEST CHARACTERISTICS

In order to guarantee that existing containers' welds are strong enough to survive the stress levels reached during a 30-ft drop, a method of proof testing is desired.

Unfortunately, internal pressurization is not a practical approach, because the internal pressures do not efficiently generate high levels of weld stress. Long before the desired proof stress level in even a small weld could be reached, the bottom plate of the container would be permanently deformed.

Alternatively, a force applied directly to the bottom plate by means of a ram and hydraulic press arrangement as illustrated in Figure B-1 could be used. This approach would largely eliminate the bending stresses caused by internal pressurization in the bottom plate, and would allow appropriate proof stress levels to be reached in the weld.

Several characteristics of the test procedure which would be desirable include the following:

1. The force applied must be accurately measurable; a calibration traceable to National Institute of Standards Technology should be provided.
2. The force applicator (ram head) should be self-aligning in case the bottom plate is not exactly perpendicular to the container axis. The applicator should apply its load in the vicinity of the weld; it should be of the largest diameter which will easily slip inside the container and not interfere with any irregularities of the container interior. The head should be strong enough not to deform or buckle upon repeated use.

3. Some containers may have effective weld sizes that could yield but not fail at the proof loads applied. Since these welds could conceivably be damaged by the test, a method is required to determine if yielding occurs without failure. Alternatives would be to (1) instrument the end plate displacement versus applied load, or (2) use a brittle coating that would flake off the weld if plastic deformation occurs. Coatings are available commercially which are compounded to flake off at strains of $\approx 0.5\%$, which level is well above the strains encountered in elastic loading ($< 0.2\%$) or which may result from partial relief of weld residual stresses.
4. Since it is possible that some ends may fail, safety precautions which preclude accidental personnel injury should be employed (an end plate "catcher" or shield).
5. The leak test to check for leak paths in the weld shall be conducted in accordance with American National Standards Institute (ANSI) 14.5 for leak tests on packages for shipment of radioactive materials. Reference ANSI 14.5 Appendix 3.4, Soap Bubble Test, for test procedure.

The container shall be pressurized to a test pressure of 14 psig for 15 min. Then with the container still pressurized, all possible leak areas of the weld will be coated with a soap solution. The solution must bridge all weld areas to be effective. Bubbling of the solution indicates a leak path in the weld. Any bubbling is cause for rejection of the container. Commercial soap solutions with low surface tensions are available for use in this leak test. After completion of the testing, the effected area will be cleaned.

112107.272

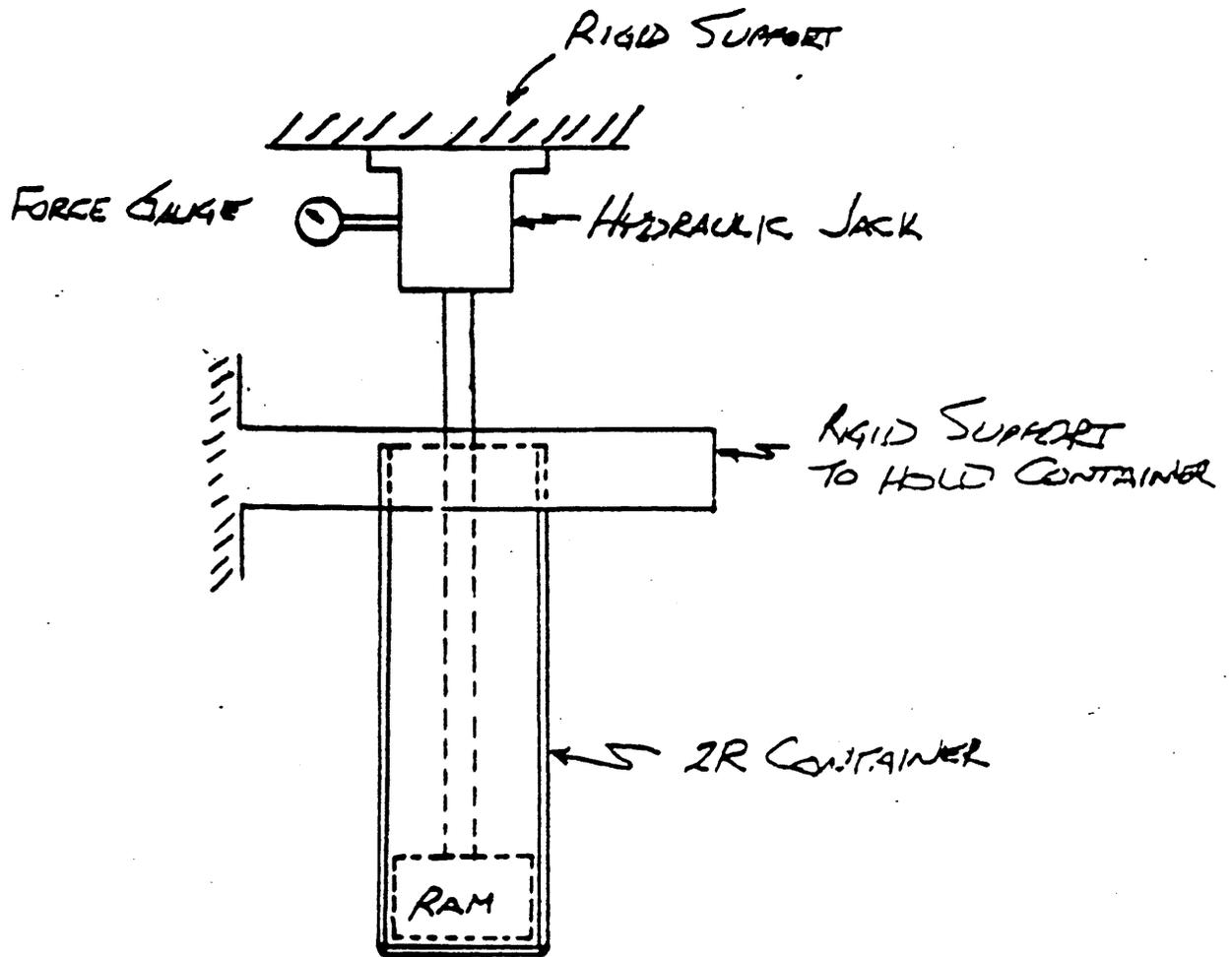


Figure B-1