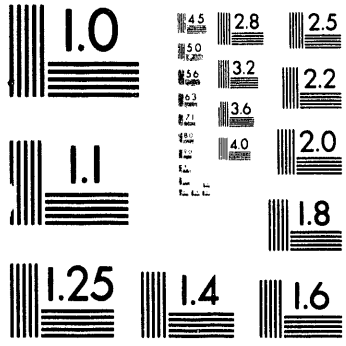
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WSRC-TR-93-328
TASK 93-031-1

STD
SAFETY TECHNOLOGY DEPARTMENT

TRU Waste Drums
Stress Analysis
Transuranic
Fracture
CAMEL
Retention - Permanent

STRUCTURAL INTEGRITY EVALUATION OF TRANSURANIC WASTE DRUMS (U) TASK NUMBER: 93-031-1

By

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DOCUMENT: WSRC-TR-93-328

TITLE: STRUCTURAL INTEGRITY EVALUATION OF TRANSURANIC WASTE DRUMS (U)

TASK: 93-031-1

TASK TITLE: STRUCTURAL ANALYSIS OF TRANSURANIC (TRU) WASTE DRUMS

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EXECUTIVE SUMMARY

Over 4400 Transuranic (TRU) waste drums have been found to contain standing rain water in the drum annulus, liner, or both. This has caused some pitting corrosion damage to the inside surface of the drums. A dewatering plan is underway to inspect these drums and determine their reusability. The drums will then be stored inside the weather enclosures to mitigate the corrosion problem. The storage and any subsequent handling may extend to next 20 years until these drums are transported for final disposal at Waste Isolation Pilot Plant (WIPP). This report evaluates the loading conditions during storage and handling at SRS to ensure that these drums maintain their structural integrity.

Structural analyses and fracture analyses have been performed in this report to evaluate the storage and handling loading conditions of the drums. The analyses are based on the observation that the general corrosion will not be a concern in the weather enclosures. However, the pitting corrosion will continue to exist. Structural analyses using finite element techniques show that the drums containing 150 lbs to 800 lbs TRU waste could be safely handled under these conditions. Fracture analyses show that a drum containing 800 lbs of TRU waste could be safely handled provided a cluster of throughwall corrosion pits is less than 4.0" long.

Some conclusions are derived from the drop tests performed at Sandia Labs. Drop tests at Sandia Labs were performed on new drums, however, some general observations can be made for the reusable SRS TRU drums (with some corrosion pitting) which are structurally sound and will have only limited corrosion in the future due to improved storage conditions. It is believed that the TRU drums, which have high ductility, will not fail (walls split apart) due to a postulated 10 foot drop. However, some drums which might develop localized pitting due to extended storage in the weather enclosures might fail in the event of a drop depending upon the location of corroded areas. In any case, Sandia tests showed that the drum contents will most likely not be exposed to the environment due to such accidental drops during handling.

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1.0 INTRODUCTION

1.1 Background

Currently a large number of TRU waste drums which contain low level mixed waste are retrievably stored on TRU waste pads in the open in E-Area interim storage. These drums will be transferred to a Waste Isolation Pilot Plant (WIPP) for final disposal at some time in future. It is expected that the interim storage will extend to about 20 years. The construction of the drums is such that rainwater collects in the lids if stored in the open. X-ray inspections of about 10,500 drums stored uncovered have revealed that rainwater has entered the annular space of about 4400 drums through the vent valve by diurnal temperature cycling. This water has caused pitting corrosion of these drums and has increased the potential of an environmental release due to loss of drum structural integrity.

The TRU drums containing water will be dewatered and reused or discarded depending upon the condition found during the dewatering process. A set of acceptance criteria for these drums is given in Reference 1. The acceptable drums will be dried, repacked, and stored inside weather enclosures. Storage under the weather enclosures will mitigate the corrosion, however, some progressive corrosion will continue due to lack of humidity controls in the enclosures. It is envisioned that this process will enable TRU drums to be safely stored for approximately another 20 years at which time they could be safely transported for permanent disposal at WIPP.

Figure 1 shows the storage arrangement of the drums inside the weather enclosures. The enclosures will provide space between stacked drums for visual inspection and retrieval of drums, if necessary.

1.2 Purpose

The analysis in this report will evaluate the structural integrity of the drums under different loading conditions including stacked storage, handling, and accidental dropping during handling. The report will document a comprehensive structural and fracture analysis to form a basis for the interim storage. This report provides a technical basis for safely storing and handling the drums during extended storage inside the weather enclosures.

1.3 Inspection of the TRU Waste Drums

An inspection plan for TRU drums is delineated in Reference 1. The inspection will include visual inspections to assess the overall structural integrity of the drums. Drums that do not have any holes due to corrosion will be reused. Drums that do not meet the inspection criteria will be safely discarded.

1.4 Material Degradation Evaluation

The primary cause of material degradation is the corrosion of the inner surface of the drum due to the presence of water in the annular space. The diurnal temperature cycling causes porosity in the galvanized coating resulting in the formation of corrosion sites on the drum surface. This is followed by well established pitting corrosion of the carbon steel. Once this occurs, rapid drum deterioration follows. A detailed corrosion study [2] of the dewatered TRU drums drew the following conclusions.

1. The corrosion rate of the Zn layer above the water level was consistently higher than the Zn layer under water. The drum lid experienced a greater Zn layer corrosion rate than the side walls or the bottom of the drum. (This is important since the lid does not carry any TRU waste loading under normal storage and handling conditions).

2. The average thickness of the drums is close to 60 mils. The average thickness of the carbon steel in the various drums varied from 55 mils to 60 mils. (This loss of metal is considered negligible to have an adverse impact on the structural integrity of the drum).
3. Pitting corrosion exists in 96% of the examined drums. Pit corrosion sites as large as 1" in length exist in 71% of the pitted drums.

This analysis did not estimate the carbon steel corrosion rate because of only minor actual carbon steel loss in the examined drums. Carbon steel corrosion rate for the storage conditions inside the weather enclosures is evaluated in a separate study [3]. The evaluation in this study estimates that the useful life of a TRU drum will vary from 9.5 years to 23 years depending upon the humidity level inside the enclosures.

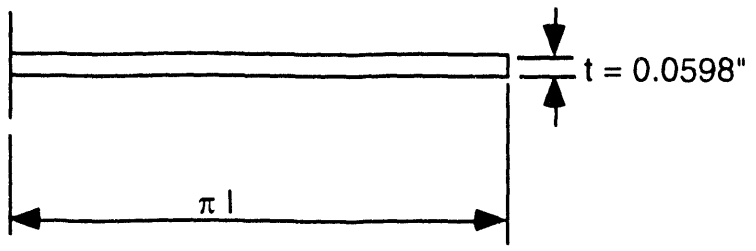
The analysis in this report assumes that the corrosion of the Zn layer will be negligibly small in the improved environment of the weather enclosures. However, the pitting corrosion at a few sites may continue at a reduced rate and may eventually breach the drum boundary.

2.0 MATERIALS OF CONSTRUCTION

2.1 Mechanical Properties for Engineering Analysis

The TRU drums are fabricated from low carbon steel [4]. The carbon content of the typical steel used in the fabrication of TRU drums varies from 0.04% to 0.073% [5]. The material is obtained in the form of sheets of 16 gauge thickness with a Rockwell B hardness of 40 to 55. Reference 4 does not specify any specific ASTM number for the material of construction and, therefore, a precise stress-strain curve of the material is not available. A reasonable estimate of the mechanical properties is made from the low carbon steel properties described in alloy steel handbooks in References 6 and 7.

Simple strain calculations are performed for the different sections of the drum to get a good estimate of the mechanical properties. The following plate model is used to calculate the plastic strains at important locations.



1. Drum Cylindrical Surface: For this case the plate is bent 360° in a circle of radius **r**. If the initial length πl is bent 360°, we get

$$\pi l = 2*\pi*r \quad \Rightarrow \quad l = 2\,r$$

$$\text{Strain} = \frac{2*\pi\,(r+t/2)-\pi l}{\pi l} = \frac{t}{l} = \frac{t}{2r} \qquad (1)$$

For a drum having a radius of approximately 12" and t=0.0598", we get

$$\text{strain} = \frac{0.0598}{24} = .0025 \text{ or } 0.25\%$$

This strain corresponds to strain at the yield point. Therefore, no cold working, roughly defined as proportional to plastic strain, is involved and the material properties of the annealed material can be used.

2. Hoops: For this case, the hoop radius **r** = 0.5". Using the strain formula in Eq. 1, we get

$$\text{Strain} = \frac{t}{2r} = \frac{0.0598}{2*0.5} = 0.06 \text{ or } 6\%$$

This localized plastic strain will cause small increase in the yield strength and ultimate strength of the material. This increase is not considered in the analysis and it is not expected to have significant impact on the final conclusions.

3. Interface between Drum Bottom and Drum Cylindrical Surface: For this case the radius **r** = 0.25" to 0.5".

$$\text{Strain} = \frac{t}{2r}$$

$$\text{For r= 0.5", strain} = \frac{0.0598}{2*0.5} = 0.06 \text{ or } 6\%$$

$$\text{For r= 0.25", strain} = \frac{0.0598}{2*0.25} = 0.12 \text{ or } 12\%$$

The bottom carries the weight of the contents and therefore, a modified stress strain curve is used in case any plastic strains occur. The edges of the bottom of the drum are bent 90° in a radius of 1/4" to 1/2" to join with the rest of the drum surface and to form the base of the drum. The bending of the circular edge of the bottom introduces an average of 9% (6 & 12%) plastic strain and, therefore, a modified stress-strain curve, shown in Figure 2, is obtained for the cold worked material using property curves (Fig. 3) from Metals Handbook [7]. The higher yield strength and tensile strength for the cold worked material are obtained from Figure 3 using 9% cold work. The modified curve is used in the plastic analysis for the heavier loading. The mechanical properties in Table 1 are obtained using estimates in Fig. 3. A value of 0.3 is used for Poisson's ratio.

Table 1 - Mechanical Properties of Low Carbon Steel

Drum Component	Temperature (°F)	Yield Strength Sy (ksi)	Tensile Strength Su (ksi)	Ductility %
Cylindrical Surface	70	30	48	40
Lid	70	30	48	40
Bottom	70	44	55	26.5
Chimes	70	44	55	26.5

Figure 2 shows the stress strain curves used in the analysis in this report.

2.2 Fracture Toughness

Fracture toughness, K_{IC}, value for the drum sheet material is not available. This material property depends upon several factors such as service temperature, ductility, environment etc. A representative value is taken for a similar low carbon plate material, A285 Grade A, used in the

fabrication of large diameter (30" or larger) piping at SRS. Minimum yield strength (24 ksi) and tensile strength (45 ksi) values for the A285 are similar to the values for the drum material. Static and dynamic fracture toughnesses for A285 material samples were determined by compact tension tests of L-Reactor archival piping at 40°F [8]. The ASTM A285 piping material had an average fracture toughness (K_{IC}) of 205 ksi$\sqrt{in}$.

The fracture toughness specimens were not thick enough to qualify as plane strain test specimens as they are from a 0.5" thick section. Fracture toughness inceases with a decrease in thickness and, therefore, this fracture toughness value is conservative for the throughwall flaws in the 0.0598" thick drum walls. Table 2 below lists the fracture properties used in the flaw evaluation analysis.

Table 2 - Fracture Toughness for Low Carbon Steel

Material	Test Temperature (°F)	Sample ASTM Orientation	K_{IC} (ksi$\sqrt{in}$)
A285 Gr A	40	C-L	205

3.0 LOADING CONDITIONS

3.1 Temperature and Pressure

The TRU drums will be stored inside weather enclosures. The buildings are ventilated and, therefore, an average temperature of 70 °F is assumed in the stress analysis. Some variation in temperature from this value will have no impact on the analysis or on the structural integrity of the drum. The waste is contained in a 90 mil thick polyethylene liner supported on the bottom. The liner is strong enough that no loading is imposed on the side walls during storage or handling of the drum .

3.2 Applied Loads

The TRU drums will be stored in two stacked high configuration, Fig. 1. Therefore, the weight loading of one filled drum will be used in the analysis concurrent with the TRU waste contents loading for the storage loading conditions. The average weight of the contents is 150 lbs. Less than 30 drums have been found to contain 200 to 300 lbs of contents. One drum was found to contain 800 lbs of sludge. The stacked drum weight loading is assumed to be uniformly distributed along the top chimes and the contents loading on the bottom. The empty TRU drum weighs approximately 60 lbs.

The drums are stored for ease of retrieval. During retrieval the drums are handled either by lifting crane, fork lifts, or fork mounted grabbers. It is postulated that the drum could fall during handling. The following loading conditions are analyzed:

1. Drums in stored condition - stacked two high (see Fig. 1)
2. Drums retrieval using lifting crane (lift by top chimes)
3. Drums retrieval by fork mounted grabbers
4. Drums dropping from a height of 10 feet during handling

4.0 ANALYSIS METHODOLOGY

4.1 Basic Assumptions

The following assumptions based on the observations in the corrosion study are made.

1. The average wall thickness of the drum will remain 0.0598" (gauge 16) due to improved storage environment in the weather enclosures.
2. The pitting corrosion will continue at few sites and may eventually result in the breach of the drum boundary. A maximum of four corrosion sites each 2" across (2 in the bottom and 2 in the side walls) are assumed in the analysis. A brief justification for selecting a total of 4 corrosion sites for the analysis is as follows:

   Corrosion analysis results [2] show that at least one significant area (≈ 1" in length) and at least one smaller area of unprotected carbon steel were found on most of the drums. Since unprotected carbon steel areas have the potential of becoming throughwall holes and larger in size in the next 20 years of storage, this observation is conservatively assumed equivalent to two 2" across areas in the bottom and two 2" across areas in the side walls of the drum.

The above assumptions are considered reasonable since the TRU drums which would be accepted for reuse after the dewatering process will have minimal visible degradation of the drum surfaces.

4.2 Storage and Lifting Conditions

Static analysis is used for the first three loading cases described in Section 3.2. The weights of the contents (150, 300, or 800 lbs) are distributed at the bottom on an imaginary circle about 1" smaller in diameter than the inside diameter of the drum. The weight of the stacked drum is distributed on the top chimes. A dynamic load factor (DLF) of 2, commonly used for suddenly applied loads, is used for all lifting loading conditions [9].

The analysis of the loading condition during drum retrieval by fork mounted grabbers is analyzed by assuming a static coefficient of friction equal to 0.7 for mild steel to steel contact [10]. If **F** is the force exerted by the grabber, μ is the coefficient of friction, and **W** is the weight of the drum, we get

$$W \times DLF = \mu \times F$$

therefore,

$$F = \frac{W \times DLF}{\mu}$$

The resulting loading **F** is distributed on the drum surface equal to the surface area of the grabber. A 6"x15" surface area of each grabber arm is assumed [11]. Drums containing up to 800 lbs of TRU waste are analyzed for the lifting conditions.

4.3 Dropped Drum Condition

No detailed finite element structural analysis is performed for this condition in this report. The analysis difficulty arise from the following reasons.

1. The interaction between the rigid liner and the drum side walls during impact is difficult to predict.
2. The mechanical properties of the drum material under dynamic loading conditions of large deformations and strain rates are not available.
3. The stress distribution at the corroded sites on the drum surfaces under dynamic loading conditions is not well understood.
4. The modeling of the lid which is banded to the top of the drum is difficult.

Some conclusions are derived based on the full scale testing of the TRU waste drums at Sandia Labs[12]. Sandia Labs have performed full scale drop tests on 55 gallon drums. These tests were performed on new drums, however, some observations from the tests can be used to predict the outcome should a TRU drum at SRS be accidentally dropped during handling. The drums weighing up to 748 lbs were dropped from a height of 68 feet on to a non-yielding surface. The drop orientation was side drop which is most likely to result in lid separation. A lid failure is defined as slippage of the C-clamp at any point in the drum circumference. A total of 17 tests were conducted. In four tests the lid separated. The inner plastic bag (inside the 90 mils thick liner) was broken in only one case and remained intact in all the others.

The test results at Sandia have shown that these drums can take very significant impacts without loss of material.

5.0 FINITE ELEMENT MODEL AND ANALYSIS

5.1 Overview

A finite element model of the TRU drum is constructed for analyzing the drum response to the various loadings. These loadings include one-drum weight and mechanical handling loads. The three dimensional finite element model can accommodate different mechanical handling and weight loads. A simplified linear elastic fracture analysis is performed to assess the critical flaw size in the highly stressed region. A throughwall flaw emanating from a corroded hole in the drum wall is postulated for the fracture analysis.

5.2 Finite Element (FE) Model

The basic dimensions (Fig. 4) for generating the FE model were taken from drawings given in drum purchase specification [4]. Several types of drums have been used over the years, however, the drawing used for the analysis is the most common drum design used at SRS. The drum side walls and the two ends of the drum are modeled with wall thickness equal to 0.0598" (gauge 16 steel [4 & 10]). The top and bottom chimes were modeled with greater thickness due to their construction. Due to the difficulty in accurately modeling the contact interface between the lid and the drum side walls at the top, the lid of the drum is modeled integral with the cylindrical surface of the drum. Since the integrity of the lid is not a concern, this simplification will not impact the final conclusions.

The effect of localized pitting was studied by postulating four typical 2" x 2" throughwall corroded areas, two in the bottom and two in the side walls of the drum. The two areas in the bottom are postulated to lie close to the high stress areas and the two areas in the sidewalls lie in the middle of the drum.

The drum is modeled with second order shell elements (Type S8R5) in ABAQUS FE Code [13] with the wall mid surface radius as the drum radius. The rolling hoops surface was measured from several types of drum surfaces and the most curved surface was used in the analysis for conservative results.

The model was generated with PATRAN [14] FE preprocessor. The PATRAN model was translated to a FE mesh for the ABAQUS code on the SRS Cray X-MP EA Supercomputer.

5.3 Finite Element (FE) Mesh

Figure 5 shows the finite element (FE) mesh of the drum. The FE mesh contains 2664 thin shell elements for the model. A total of 8159 nodes were used in the model. Only half of the drum surface was modeled to take advantage of the symmetry of the drum surface and the loading

conditions. The outer edge of the drum bottom is modeled with 1/2" radius to approximate the crevice space between the bottom head and the drum cylindrical surface. The crevice space is filled with some compound to minimize crevice corrosion and is not considered in this analysis.

5.4 Material Idealization

The material of construction for the TRU drum is a low carbon steel. At 70 °F, Young's modulus is 27.9 x 10^6 psi. The stress-strain curve for this was not available. A simplified bilinear curve as shown in Fig. 2 is assumed for the cylindrical surface of the drum The cold work due to bending of the edge of the drum bottom increases the yield stress and the tensile strength of the material close to the edge and, therefore, a slightly different stress strain curve with higher yield stress and tensile strength values as shown in Fig. 2 is assumed. This curve was obtained as explained in section 2.1.

5.5 Boundary Condition

The boundary conditions depend upon the loading analyzed. The boundary condition due to symmetry about plane X = 0 (Fig. 5) is common to all the loadings. The following additional boundary conditions were applied.

1. For storage conditions, no displacement in the Y-direction at the base of the drum. Node 1 (Fig. 5) was fixed in all degrees of freedom to prevent rigid body motion of the FE model.

2. For lifting conditions from the top rim of the drum during handling, the two nodes 180° apart, at the top were fixed to prevent any rocking and rigid body motion.

3. For lifting condition using the fork mounted grabbers, the nodes in the grabber area were restrained in the Y-direction. Node 1 was restrained (except in Y direction) to prevent rigid body motion of the FE model.

5.6 TRU Drum Analysis

5.6.1 Drum Stress Code Check

For the two-stacked high storage configuration, the drum is subjected to a combined loading of one drum weight and the weight of the TRU waste in the liner. A review of the detailed stresses (Table 3) documented in computer outputs in Items 1 through 10 of Appendix A shows that for loading conditions of storage, the stresses are highest at the interface of the drum bottom with the cylindrical surface . However, the stresses are maximum in the cylindrical wall area for the loading condition in which the drums are lifted by the crane or by the fork mounted grabbers. Code stress check will be carried out only for the loading condition with maximum stress intensity, S, which occurs during lifting of drums containing 800 lbs of waste by fork mounted grabbers.

The drum is a non-safety class component. Therefore, ASME Code Section VIII Appendix 4 [15] is used for the code stress check. The maximum stress intensity is calculated from the principal stresses σ_1, σ_2, and σ_3. The σ_1, σ_2, and σ_3 are the minimum, intermediate, and maximum principal stresses and are given in the ABAQUS computer runs listed in Appendix A. The principal stresses are then combined to obtain stress intensity S [15] as follows:

$$S = \mathrm{Max}(\,|\sigma_1 - \sigma_2|,\ |\sigma_2 - \sigma_3|,\ |\sigma_3 - \sigma_1|\,)$$

These S values for drums containing 800 lbs of waste are summarized in Table 3. Stresses are also summarized for 300 lbs loading conditions for comparison with drums having 2" x 2" holes.

Table 3 - Calculation of Maximum Stress Intensity

Drum Analysis	Contents Weight	Element No. †	S_{11} (psi) ††	S_{22} (psi)	σ_1 (psi)	σ_2 (psi)	σ_3	S (psi)
Storage (Sidewalls)	800	1135 (I) 1135 (O)	684 2326	-2983 2598	-2984 0	0 2326	684 2598	3668 2598
Storage (Bottom)	800	2205 (I) 2205 (O)	5255 -5479	5955 -6314	0 -9469	2539 -2325	8671 0	8671 9469
Lifting (Crane) (Sidewalls)	800	1693 (I) 1693 (O)	-213 -11782	22665 -20336	-215 -20336	0 -11781	22667 0	22881 20336
Lifting (Crane) (Bottom)	800	2202 (I) 2202 (O)	7343 -7781	14899 -15956	0 -18956	4910 -4781	17332 0	17332 18956
Lifting (Grab) (Sidewalls)	800	558 (I) 558 (O)	-2771 -22386	28401 -28624	-2782 -28627	0 -22383	28412 0	31194 28627
Lifting (Grab) (Bottom)	800	2250 (I) 2250 (O)	4657 -6060	19324 -20735	0 -20768	4634 -6027	19347 0	19347 20768
Lifting (Crane) (Sidewalls)	300	1693 (I) 1693 (O)	-78 -4919	9491 -8517	-79 -8517	0 -4919	9491 0	9570 8517
Lifting (Crane) (Bottom)	300	2202 (I) 2202 (O)	2513 -2689	6076 -6541	0 -7340	1872 -1883	6729 00	6729 7340
Lifting (Crane) w/ 2"x2" Holes	300	1693 (I) 1693 (O)	-76 -4913	9485 -8512	-76 -8512	0 -4912	9485 0	9561 8512
Lifting (Crane) w/ 2"x2" Holes	300	2202 (I) 2202 (O)	-2928 -3238	6012 -6419	0 -7632	1884 -2025	7057 0	7057 7632

† See ABAQUS computer runs in Appendix A. (I) and (O) are the inside and outside surfaces of the elements. 2200 series element numbers are in the bottom of the drum, and the remaining are in the sidewalls of the drum.
†† S_{11} and S_{22} are the normal stress components.

A review of the stresses shows that there is considerable bending across the thickness of the elements. The value S includes local membrane stress, P_L, and local bending stresses, Q, described in the Table 4-120.1 of Reference 15. The characterization of S is based on the fact that the stress distribution is local and through the thickness of the drum wall. For the storage conditions, the maximum stress intensity, S, occurs on the drum bottom close to the edge. For the lifting condition by crane or fork mounted grabbers, the maximum stress intensity occurs in the cylindrical surface of the drum. Handling by grabbers represents the worst loading condition and will be analyzed for the Code stress check.

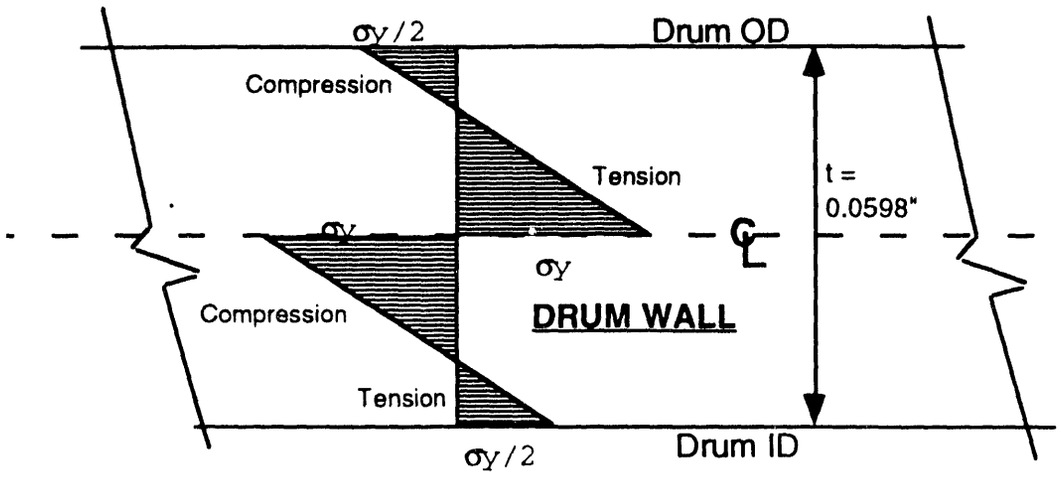
A review of the maximum stresses for the case of loading with holes in the drum surface shows that the maximum stresses are similar to the case of loading with no holes. This is an important observation in that the maximum stresses are not significantly affected by few weak areas of the drum surface due to corrosion. Therefore, maximum stresses from the analyses with no holes can be used for analysis purposes.

Local membrane stress P_L is calculated by taking the average of the maximum stress intensity, S, values, given above, through the thickness.

$$P_L = \frac{31194-28627}{2} = 1284 \text{ psi}$$

and $$Q = S - P_L = 31194 - 1284 = 29910 \text{ psi}$$

Any residual stresses induced during fabrication of the drum are difficult to determine due to the variation in the fabrication processes of the different vendors. A simple fabrication process will involve rolling a metal sheet into a cylindrical shape along with the hoops and then seam welding the two ends. This operation will induce tensile stresses equal to the flow stress of the material on the outside of the formed surface and compressive stresses on the inside surface. If it is assumed that the material hardening is small due to small plastic strain, this process will result in surface residual stresses equal to approximately half the yield strength of the material [16]. A typical residual stress distribution based on this model is shown below.



Residual Stress Distribution at the Side Walls

It should be noticed that the residual stresses at the outer surface of the drum are compressive if the initial stress during fabrication is tensile. This state of stress is beneficial to prevent any crack initiation at the outer surface.

The residual stresses are classified as secondary stresses, Q, in the ASME Code [15]. Therefore, total Q is,

$$Q = 29910 + Sy/2 = 29910 + 30000/2 = 44910 \text{ psi}$$

The following stress limits from Figure 4-130.1 of the ASME Section VIII Code [15] apply for the applied loading during normal storage conditions.

$$P_L = 1284 \leq 1.5\ Sm = 24000 \text{ psi; and}$$
$$Q + P_L = 44910 + 1284 = 46194 \leq 3\ Sm = 48{,}000 \text{ psi}$$

where Sm = 16000 psi from Table ACS-1 of the ASME Section VIII Code [15] for carbon steel with Sy=30000 psi and Su=48000 psi. An Sm = 15000 psi (lowest value in Table ACS-1) will make Q + P_L exceed the stress limit of 3Sm by 2.65% but this is acceptable since the stresses are secondary (important for fatigue) in nature and the loading is quite conservative (800 lbs and DLF=2).

The drum design meets the ASME Section VIII Code [15] requirements.

5.6.2 Drum Fracture Analysis

Three types of defects are envisioned on the drum surface. They are: 1) corrosion pits or surface indentations, 2) crack like indications or surface scratches and 3) cracks emanating from corrosion

pits or indentations. Corrosion pits and surface indentations do not have sharp edges and are analyzed by classical structural mechanics rules. However, cracks and scratches are characterized by a sharp leading edge with high stress concentrations and are analyzed by fracture mechanics. In general, fracture mechanics analyses involving cracks and scratches give more limiting results than the structural analyses involving similar size (length and depth) corrosion pits or surface indentations. The analysis in this report will include cracks emanating from corrosion pits.

Inspection of the failed drums has revealed corrosion pits through the wall. These corrosion pits act as stress risers which could result in crack like indications emanating from the boundaries of these pits. A cluster of pits could result in a throughwall hole over a period of time. In the fracture analysis such clusters are assumed as holes from which the crack could emanate.

Parameters involving flaw growth due to the presence of corrosive environment are not defined at this time and, therefore, crack growth is not analyzed in this report.

Calculation of K_I

A simplified linear elastic fracture mechanics model defined on page 19.8 of Reference [17] is used to calculate the applied stress intensity factor, K_I. A critical flaw size is reached when $K_I = K_{IC}$, where K_{IC} is the fracture toughness of the material as given in Table 2. The fracture model consists of a large plate with a throughwall crack emanating from the edge of a throughwall hole in the walls or bottom of the drum (Fig. 6). The stress intensity factor due to simple tensile load for such a crack is [17]:

$$K_{Im} = \sigma_m \times (\pi a)^{0.5} \times F_I\left(s, \frac{c}{b}\right)$$

Where,

σ_m = far field membrane stress perpendicular to the crack, psi
a = length of the crack (see Fig. 6), in
$F_I(s, \frac{c}{b} = 1) = 3.3685 - 6.4716s + 5.8194s^2 - 1.7130s^3$ (curve fitting)
$s = \frac{a}{a+b}$
c = half size of the corroded hole (see Fig. 6) = 1"
b = half size of the corroded hole (see Fig. 6) = 1"

Range of applicability of the above formulation $s \leq 1.0$

A review of the maximum stresses shows that the stresses vary through the thickness of the drum wall. Therefore, bending stresses are present and will make some contribution to the overall stress intensity factor. Any contribution due to bending stresses is estimated as:

$$K_{Ib} = \frac{(1+\nu)}{(3+\nu)} \times \sigma_b \times (\pi a)^{0.5} \times F_I\left(s, \frac{c}{b}\right) \qquad [18]$$

Where,

σ_b = far field bending stress, psi

Therefore, $K_I = K_{Im} + K_{Ib}$

Table 4 gives the maximum principal stresses and the resulting membrane and bending stresses in the highly stressed region. Since the direction of the flaw is not known, the use of maximum principal stress will bound the maximum tensile stress in any direction. Since the presence of four 2" x 2" holes does not change the maximum stresses significantly (Table 3), maximum stresses for fracture analysis are obtained from the case of unpitted drum surface in Table 3.

The above formulation is for an infinite plate with cracks emanating from a throughwall hole. Since the drum plate is finite, a maximum combined crack length (2a) of about 10% of the drum circumference will be considered in the fracture analysis.

Table 4 - Maximum Principal Stresses

Loading Condition	Element Number (location) (†)	Max Principal Stress (Inside) (psi)	Max Principal Stress (Outside) (psi)	σ_m (psi)	σ_b (psi)
Lift 800 lb Drum (Crane)	2202 (Bottom)	17332	0	8666	8666
Lift 800 lb Drum (Crane)	1693 (side wall)	22667	0	11334	11334
Lift 800 lb Drum (Grab)	2250 (Bottom)	19347	0	9674	9674
Lift 800 lb Drum (Grab)	558 (side wall)	28412	0	14206	14206

† See ABAQUS computer runs in Appendix A.

The flaw acceptance criterion is based on ASME Section XI, Articles IWB 3610 and 3620 [19] for ferritic material components with thickness less than 4". The acceptance criterion is as follows:

$$K_I \text{ (max)} \leq K_{IC}/\sqrt{10} = \frac{205}{\sqrt{10}} = 64.83 \text{ ksi}\sqrt{\text{in}}$$

The results of the fracture analysis in the order of loading conditions shown in Table 4 are given in Table 5.

TABLE 5 - Fracture Analysis Results

Flaw Length a (in)	s	F(s,1)	K_{Im} ksi(in)^.5	K_{Ib} ksi(in)^.5	$K_I=K_{Im}+K_{Ib}$ ksi(in)^.5
FLAW LOCATION - BOTTOM, $\sigma_m = \sigma_b$ = 8666 psi					
1.00	0.50	1.37	21.10	8.31	29.41
1.50	0.60	1.21	22.77	8.97	31.74
2.00	0.67	1.13	24.61	9.70	34.31
2.50	0.71	1.09	26.49	10.44	36.93
3.00	0.75	1.07	28.35	11.17	39.52
3.50	0.78	1.05	30.16	11.88	42.04
4.00	**0.80**	**1.04**	**31.91**	**12.57**	**44.48**
FLAW LOCATION - SIDEWALLS, $\sigma_m = \sigma_b$ = 11334 psi					
1.00	0.50	1.37	27.59	10.87	38.46
1.50	0.60	1.21	29.78	11.73	41.52
2.00	0.67	1.13	32.19	12.68	44.87
2.50	0.71	1.09	34.64	13.65	48.29
3.00	0.75	1.07	37.07	14.61	51.68
3.50	0.78	1.05	39.44	15.54	54.98
4.00	**0.80**	**1.04**	**41.73**	**16.44**	**58.17**

TABLE 5 - Fracture Analysis Results - Cont'd

Flaw Length a (in)	s	F(s,1)	K_{Im} ksi(in)^.5	K_{Ib} ksi(in)^.5	$K_I=K_{Im}+K_{Ib}$ ksi(in)^.5
FLAW LOCATION - BOTTOM, $\sigma_m = \sigma_b$ = 9674 psi					
1.00	0.50	1.37	23.55	9.28	32.83
1.50	0.60	1.21	25.42	10.02	35.44
2.00	0.67	1.13	27.47	10.82	38.30
2.50	0.71	1.09	29.57	11.65	41.22
3.00	0.75	1.07	31.64	12.47	44.11
3.50	0.78	1.05	33.66	13.26	46.93
4.00	**0.80**	**1.04**	**35.61**	**14.03**	**49.65**
FLAW LOCATION - SIDEWALLS, $\sigma_m = \sigma_b$ = 14206 psi					
1.00	0.50	1.37	34.58	13.63	48.21
1.50	0.60	1.21	37.33	14.71	52.04
2.00	0.67	1.13	40.34	15.90	56.24
2.50	0.71	1.09	43.42	17.11	60.53
3.00	**0.75**	**1.07**	**46.47**	**18.31**	**64.78**

TABLE 6 Summary of Fracture Analysis Results

Handling Condition	Allowable Flaw Length, a (in)	K_I (ksi$\sqrt{in}$)	Flaw Location
Lifting by Crane from Top	4.00	44.48	Bottom
Lifting by Crane from Top	4.00	58.17	Sidewalls
Lifting by Side Grabbers	4.00	49.65	Bottom
Lifting by Side Grabbers	3.00	64.78	Sidewalls

6.0 ACCEPTANCE CRITERIA FOR TRU DRUM AT DEWATERING

Due to the large number of TRU waste drums which need to be inspected during the dewatering program, the acceptance criteria has to be simple and fast to be cost effective. It is, therefore, proposed that only visual examination be performed for the flaws due to corrosion. The following acceptance criteria are suggested for visual inspection during the dewatering process.

1. Visually inspect the interior of the drum to ensure that the galvanizing protection layer is not badly deteriorated.

2. If there are clusters of corrosion pits, make sure that they are not more than about 2" across. There should not be any noticeable reduction in wall thickness at these locations. There should be no more than two such clusters in the bottom and two in the sidewalls of the drum.

3. If the corrosion pits are clustered in a line, they should be no longer than 3" to 4" in length. The inline and the 2" across clusters of pits could be connected.

7.0 CONCLUSIONS

1) Structural analysis shows that the TRU waste drums containing 150 lbs to 800 lbs of TRU waste will continue to retain their structural integrity even if drum walls have some corroded patches.

2) Structural analysis shows that the drums can be handled safely in the E-Area or weather enclosures without loosing structural integrity. Conservative fracture analysis shows that the drums containing up to 3" to 4" long in line cluster of throughwall corrosion pits will be considered having structural integrity.

3) Full size impact tests at Sandia Labs simulating dropping the drum from a height of as high as 68' show that drums have enough ductility and will safely contain the waste. From the observations at Sandia Labs, it is reasonable to conclude that a drop from a height of 10' during handling in E-Area or in weather enclosures will not cause catastrophic (walls splitting apart) failure of the drum. However, the falling drum will be grossly deformed and the drum lid might separate from the drum due to the shift in the weight of the contents during the fall.

8.0 REFERENCES

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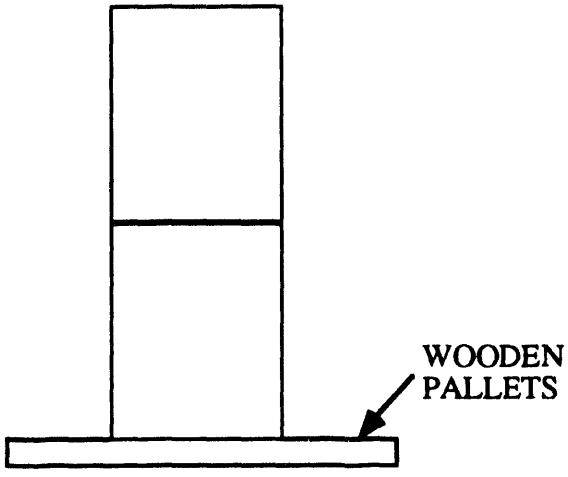


TWO STACKED HIGH STORAGE

FIGURE 1 - TRU DRUM STORAGE CONFIGURATION

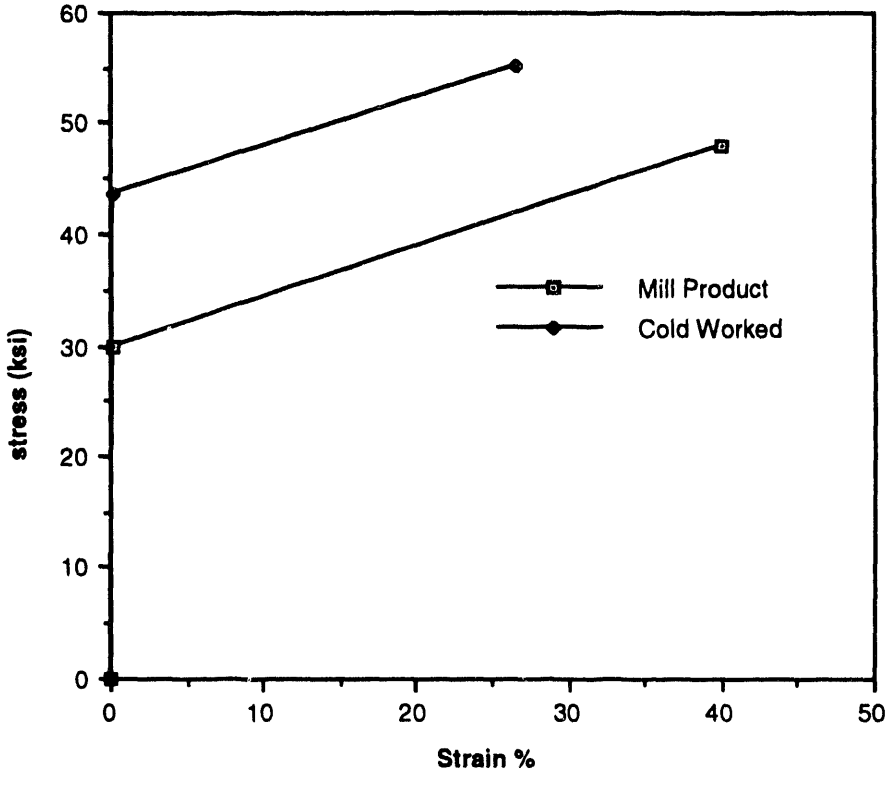
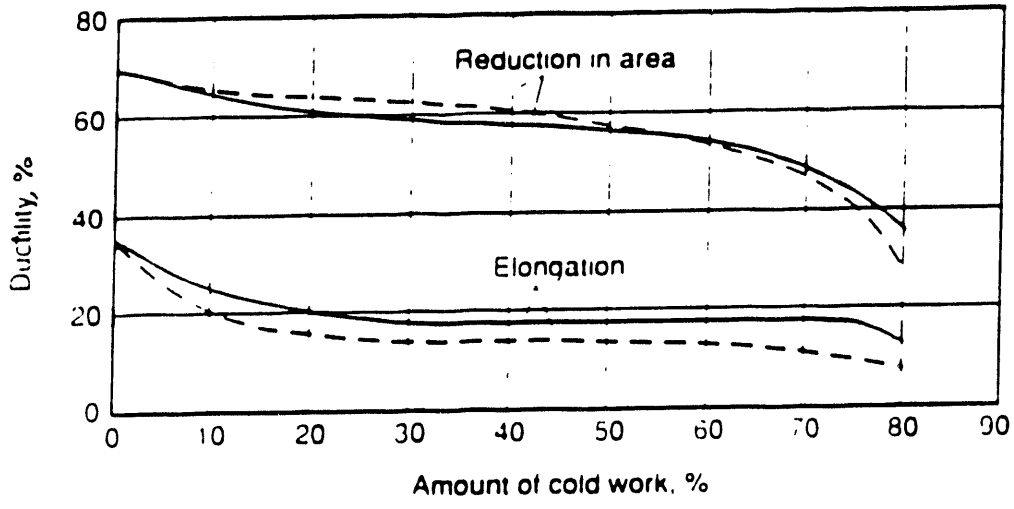
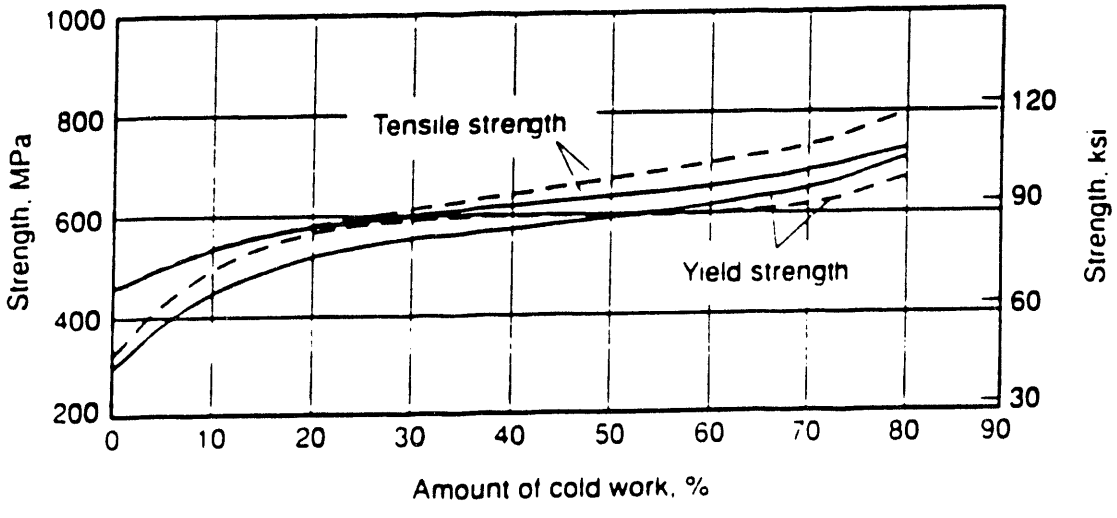


FIGURE 2 - STRESS - STRAIN DATA





Note: Dashed curves represent cold-drawn material; solid curves, material cold-drawn and stress relieved.

FIGURE 3 - YIELD AND TENSILE STRENGTH DATA

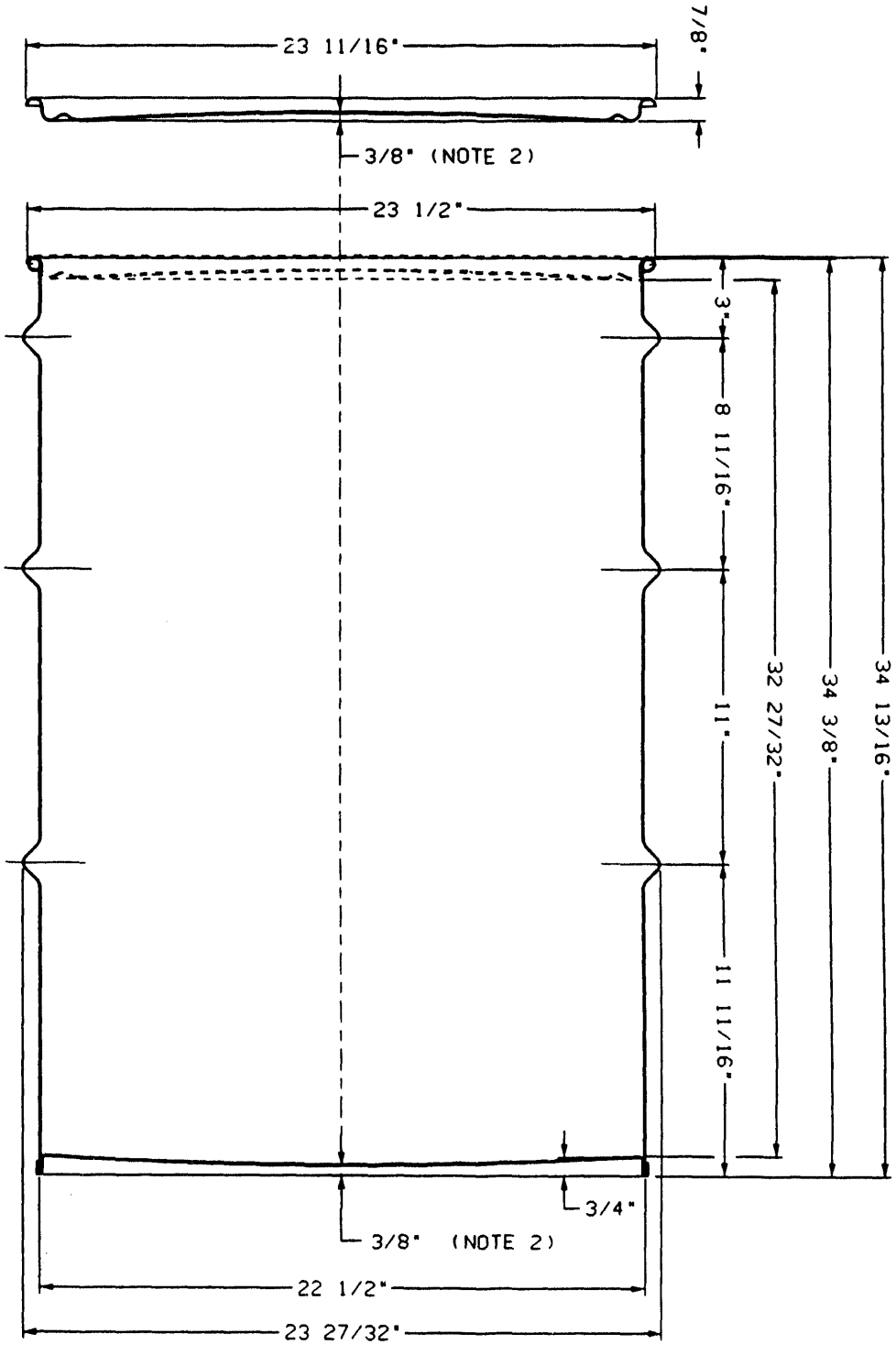


FIGURE 4 - TRU DRUM GEOMETRY

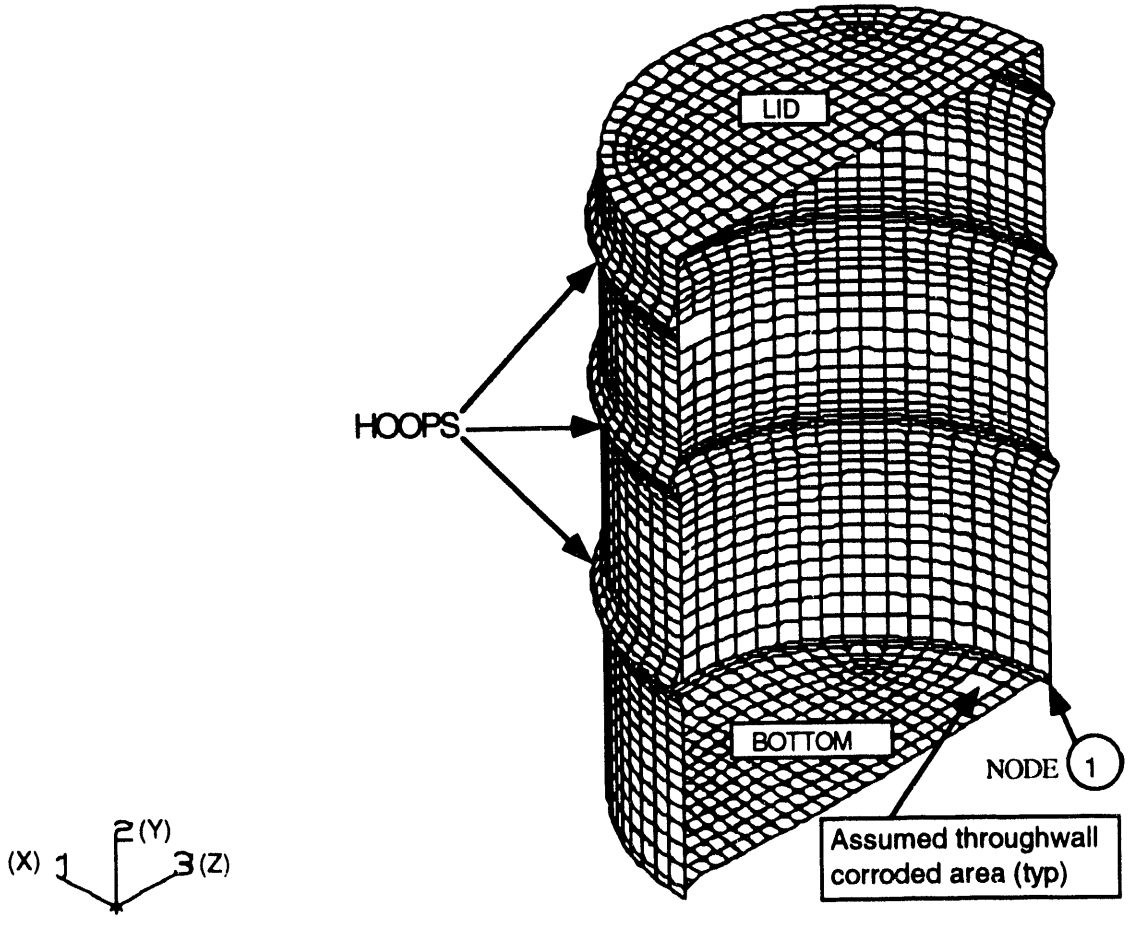


FIGURE 5 - FINITE ELEMENT MESH OF THE DRUM

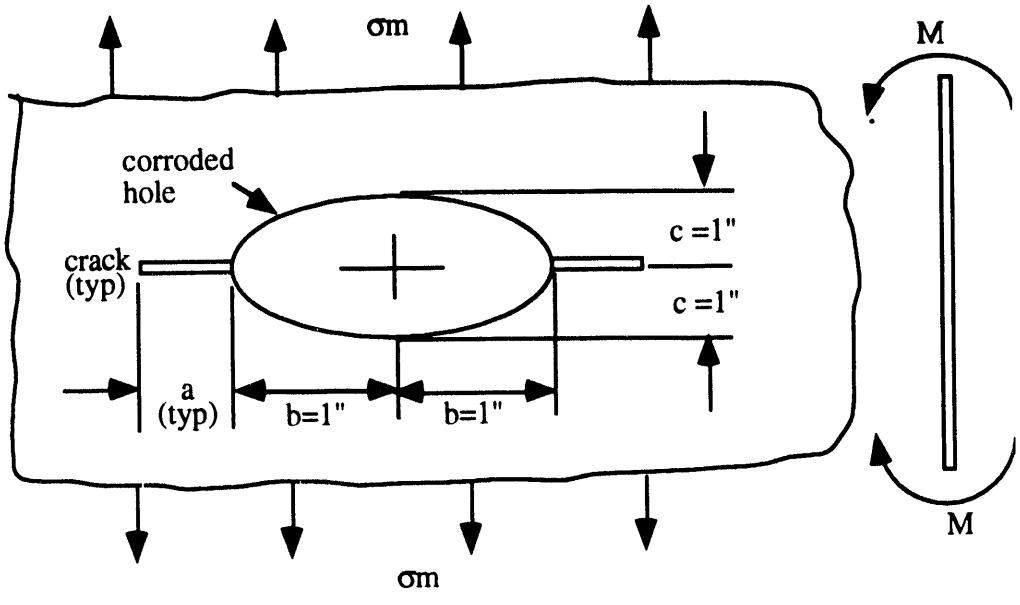


FIGURE 6 - TRU DRUM BOTTOM CRACK MODEL

APPENDIX A

TABLE OF ABAQUS COMPUTER RUNS

Item No.	Output (.DAT) File	Restart (.RES) File	File Description
1	STR150	STR150	Store 150 lb drum with Two Stacked Drums
2	STR300	STR300	Store 300 lb drum with Two Stacked Drums
3	STR800	STR800	Store 800 lb drum with no stacking
4	LIFT150	LIFT150	Lifting 150 lb drum by Crane
5	LIFT300	LIFT300	Lifting 300 lb drum by Crane
6	LIFT800	LIFT800	Lifting 850 lb drum by Crane
7	GRAB150	GRAB150	Lifting 150 lb drum by fork mounted grabbers
8	GRAB300	GRAB300	Lifting 300 lb drum by fork mounted grabbers
9	GRAB800	GRAB300	Lifting 800 lb drum by fork mounted grabbers
10	PITS300	PITS300	Analysis with 2" x 2" throughwall holes

DATE
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2/10/94

END