POLYETHYLENE

AND

ITS SUITABILITY FOR USE IN

HIGH INTEGRITY CONTAINERS

PREPARED BY

SCDHEC

BUREAU OF RADIOLOGICAL HEALTH

RAD MATERIALS SECTION

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PREFACE

The following paper is in response to certain allegations on the unsuitability of a material called cross-linked polyethylene for its use in high integrity containers.

High integrity containers are used to bury low-level radioactive waste at the three disposal facilities in the United States, one of which is located in Barnwell, South Carolina. There are currently six marketers of polyethylene high integrity containers, one of which is NUS Process Services Corporation, now known as LN Technologies.

A report was formulated for NUS Process Services Corporation by a firm called Engineering Design and Testing Corporation. This report indicates that polyethylene containers with a wall thickness of less than two inches will fail by stress cracking under the burial load conditions at the Barnwell facility.

Included herein are the assertions made by NUS, responses to these assertions by other high integrity container vendors, the Bureau of Radiological Health's comments, and the Bureau's own analytical analysis for a given size container.

HISTORY

On September 5, 1986, LN Technologies, Inc. (LNT), formerly NUS Process Services Corporation, submitted a report prepared by Engineering Design and Testing Corporation (EDTC) entitled "An Assessment of Polyethylene as a Material for Use in High Integrity Containers." This report implied that polyethylene containers used for disposal of radioactive waste with a wall thickness of less than two inches would not survive the burial conditions at the low level waste disposal facility in Barnwell, South Carolina.

The Bureau of Radiological Health of the South Carolina Department of Health and Environmental Control (BRH) performed a preliminary review of the EDTC report and, on October 24, BRH sent to all polyethylene high integrity container vendors (poly HIC vendors), a copy of the EDTC report and a letter requesting evaluation of this report as applicable to their HICs by December 15. Appendix E was omitted from the EDTC report because it was marked proprietary. Nearly all vendors responded by stating that a complete review could not be performed without the calculations and computer model located in Appendix E.

On November 13, BRH requested release of the proprietary information to the poly HIC vendors. LNT responded on November 17, stating that they would only release the information in a joint meeting with HIC vendors and BRH. These terms were unacceptable.

On December 12, BRH notified all poly HIC vendors of LNT's refusal to release the proprietary portion of the EDTC report and requested them to complete their review with the information they had. The deadline was extended to January 15, 1987. On the same day, BRH requested several references from LNT that were used in the EDTC report in order to facilitate our own review. Copies of the reference material were received on January 14, 1987.

All responses were received from poly HIC vendors by Jan. 29 and a culmination of their responses is included in the next section of this paper.

RESPONSES

This section will focus, on a point by point basis, on the LNT assumed shortcomings of using polyethylene as a material for HICs as stated in the EDTC report. There are five different vendors other than LNT currently certified to market poly HICs.

Assertion 1: Design analysis of a large cylindrical (6 x 6) unreinforced polyethylene HIC indicates that a shell thickness of nearly two inches would be required to effectively avoid buckling of the sides during isolated burial and buckling of a shallow spherical top head when buried in clusters. Shell thicknesses of this magnitude are not economic. Existing designs employ shell thicknesses considerably less than two inches.

Vendor Response A: It is a general consensus among HIC vendors that buckling is not a mode of failure.

Vendor Response B: All vendors agree that the masonry arch, as described in the EDTC report, is not a valid assumption based on backfill procedures, soil types, and the space between the containers.

BRH Response A: BRH defines failure as a loss of container contents. Many of the formulas used in the EDTC report assume failure at buckling or deformation. This is overly conservative considering the type of material being used.

BRH Response B: Containers are compression tested to at least 21 psi. In actuality, 16 psi, which is derived from an actual overburden of 19 feet, would be a more realistic pressure to use for analysis. The factor of 1.3 has already been incorporated into the container design. Dividing 21 by 16 yields a factor of 1.3 .

BRH Response C: The EDTC report also incorporates a safety factor of two into its design of a container using ribs for added support. These two additional safety factors seem overly conservative for a material such as polyethylene which is capable of some stress relaxation. As previously stated, there are several safety factors already incorporated into the design

Assertion 2: Design analysis further indicates that the bottom head should be designed to the same structural requirements as the top head. To effectively avoid failure by buckling, a shallow spherical bottom head would require a thickness of nearly two inches. Existing designs employ flat bottoms. Design analysis of this condition indicates that the expected failure mode is stress rupture and that a material thickness of at least two inches would be required to avoid failure by this mechanism. Existing designs employ shell thicknesses considerably less than two inches.

BRH Response: In addition to the responses to assertion 1, all prototype tests indicate that the containers will withstand a much greater load without loss of contents than BRH or the Nuclear Regulatory Commission requires. The poly HIC vendors and BRH are in agreement on this point.

Assertion 3: Initial buckling of a HIC would set up conditions of highly localized stress in the container wall. This situation would in turn lead to failure of the wall by a mechanism of stress rupture.

Vendor Response A: Four of the vendors pointed out that the EDTC report did not consider the stress relaxation properties of polyethylene where localized stresses are relieved by creep of the container material.

Vendor Response B: Three vendors pointed out that the curve provided by the EDTC report shows a stress rupture value of approximately 2100 psi, but it indicated that a value of 700 psi should be used for design purposes. All vendors feel this is overly conservative, and most of the containers are under 700 psi anyway.

Vendor Response C: In reference to the number of points used for extrapolation to 300 years, one vendor pointed out that there are just as many data points for irradiated and non-irradiated samples, the latter of which the EDTC report uses for the 700 psi value. Also, a linear plot may not be valid. A curve may be more appropriate, and this would yield a value twice that given by EDTC.

BRH Response: BRH agrees that highly localized areas of stress would eventually cause the container to fail due to stress cracking. However, we do not feel that the conditions exist to create this type of highly localized stress in the container due to the stress relaxation properties of polyethylene and the existing burial load conditions at the Barnwell facility.

Assertion 4. Chemicals within the container can be expected to develop conditions which are detrimental to polyethylene by promoting environmental stress cracking and a reduction in stress rupture values. Designs must account for this reduced strength.

Vendor Response A: All vendors agree that strict controls at nuclear facilities inhibit the introduction of harmful chemicals into the HICs. Even if introduced, they would be in very low concentrations. Also, by license conditions at Chem-Nuclear, many of these chemicals are prohibited unless made non-corrosive.

Vendor Response B: Three vendors address the radiation exposure aspect as well as chemical. It is agreed, even by the EDTC report, that polyethylene will increase in strength with exposure to radiation up to 10^8 rads. This will provide greater resistance to cracking, but will also cause the material to become less ductile. However, the rate of exposure at 300 years will be almost background, and failure at this stage would have little or no consequence.

BRH Response: By license conditions at the Barnwell facility, many of the chemicals that could be harmful to polyethylene, such as scintillation fluids, are prohibited. We also believe that the strict controls and monitoring at nuclear plants tend to minimize and eliminate these chemicals in the waste streams. The chemical resistance of polyethylene is well known, and BRH does not feel this is a problem.

Assertion 5. Currently available creep and stress rupture data on polyethylene is available in periods up to one year. Designs must therefore be based on data which has been extrapolated an additional 299 years for a required 300 year life. Extrapolations of this magnitude are subject to considerable error.

Vendor Response A: One vendor states that interpolations of this magnitude are not unique to polyethylene and do not prove that the HICs will fail.

Vendor Response B: Another vendor points out that the linear interpolation that the EDTC report used was no more valid than any other. The same number of data points were used to derive the value of 700 psi.

Vendor Response C: Another vendor states that Brookhaven's tests were favorable although the tests were performed on samples bent into U-shapes. When extrapolated to 300 years, these results yielded a value of 2100 psi. Phillips Chemical Company, the manufacturer of Marlex CL-100, demonstrated an allowable stress of 2600 psi when exposed to various simulated waste streams.

BRH Response: BRH believes that the strength value of 700 psi is not a valid assumption. The linear plot in the EDTC report may not be accurate (ref.3). The points for the non-irradiated samples tend to fit a curve which would yield a value higher than the value given by EDTC, approximately 1523 psi for samples tested in air and 1269 psi for the samples exposed to various waste streams. We feel that the value of 2100 psi for the irradiated samples is valid until proof can be provided otherwise.

STRESS ANALYSIS

The following analysis shows BRH's stress calculations for a 6ft x 6ft toroshperical top high integrity container buried at the low-level waste disposal facility in Barnwell, South Carolina. The following container dimensions are for this analysis only. All other characteristics of polyethylene and the disposal conditions are found on page 13.

Container Diameter	d_o = 6 ft. or 72 in.
Container Radius	R_o = 3 ft. or 36 in.
Container Height	h_c = 6 ft. or 72 in.
Wall Thickness	t_w = 0.75 in.
Soil Overburden	h_s = 25 ft.

1. Load due to overburden

$$q = p_s h_s = (120 \text{ pcf})(25 \text{ ft})/(144 \text{ in}^2/\text{ft}^2)$$
$$q = 21 \text{ psi}$$

2. Total force on container top

$$F_t = qA_t = (21 \text{ psi})\pi(36 \text{ in})^2$$
$$F_t = 85{,}502 \text{ lbs.}$$

3. Cross-sectional area of wall

$$A_w = 2\pi R_o t_w = 2\pi(36 \text{ in})(0.75 \text{ in})$$
$$A_w = 170 \text{ in}^2$$

4. Compressive stress in dome top

reference 1, page 453, case 3e
assume radius of curvature of toroshperical dome is twice the container radius

$R_2 = 2R_o = 72$ in.

$s_{ct} = qR_2/2t_t = (21 \text{ psi})(72 \text{ in})/2(0.75 \text{ in})$
$s_{ct} = 1008$ psi

$FS = (s_{ca}/s_{ct})$
$FS = (1500 \text{ psi}/1008 \text{ psi}) - 1 = 0.49$

5. Compressive stress in the container wall

$s_{cw} = F_t/A_w = 85{,}502 \text{ lbs}/170 \text{ in}^2$
$s_{cw} = 503$ psi

$FS = (s_{ca}/s_{cw})$
$FS = (1500 \text{ psi}/503 \text{ psi}) - 1 = 1.98$

6. Allowable buckling stress in the container wall

reference 1, page 555, case 15
for $R_o/t_w > 10$ and $h_c >> 1.72(R_o t_w)^{.5}$

$R_o/t_w = 36 \text{ in}/0.75 \text{ in} = 48 >> 10$
$1.72(R_o t_w)^{.5} = 1.72((36 \text{ in})(0.75 \text{ in}))^{.5} = 8.94 << 72$ in

Experimental results indicate that failure occurs at 40 to 60 percent of theoretical. Therefore

6. Continued.

$s_{cr} = 0.4Et_w/(3(1-v^2))^{.5}R_o$
$s_{cr} = 0.4(100,000 \text{ psi})(0.75 \text{ in})/(3(1-0.45^2))^{.5}(36 \text{ in})$
$s_{cr} = 539 \text{ psi}$

$FS = (s_{cr}/s_{cw})$
$FS = (539 \text{ psi}/503 \text{ psi}) - 1 = 0.072$

7. Hoop stress in the container wall

reference 2, page 74
assume extreme condition of soil density = 120 pcf

$P = 3p_s h_c = 3(120 \text{ pcf})(6 \text{ ft})/144 \text{ in}^2/\text{ft}^2$
$P = 15 \text{ psi}$

$s_h = PR_o/t_w = (15 \text{ psi})(36 \text{ in})/ 0.75 \text{ in}$
$s_h = 720 \text{ psi}$

$FS = (s_{ta}/s_h)$
$FS = (2600 \text{ psi}/720 \text{ psi}) - 1 = 2.61$

8. Deflection in the container bottom due to the compaction of the soil below the container

reference 4, figure 6

$y = 4q_w B^2/K_{v1}(B + 1)^2$

$q_w = (F_t)(144 \text{ in}^2/\text{ft}^2)/(A_w)(2000 \text{ lbs/ton}) = 36.2 \text{ tsf}$
$y = 4(36.2 \text{ tsf})(0.75 \text{ in})^2/(235 \text{ tons/ft}^3)(0.75 \text{ in} + 1)^2$
$y = 0.113 \text{ ft.} = 1.4 \text{ in.}$

9. Diaphram stress in the bottom

reference 1, page 406 solving equation 2 for stress

$$s_d = Et_b^2 k_4 y^2 / R_o^2 t_b^2 = Ek_4 y^2 / R_o^2$$

using case 4 from page 407

$$s_d = (100{,}000 \text{ psi})(0.965)(1.4 \text{ in})^2/(36 \text{ in})^2$$
$$s_d = 146 \text{ psi}$$

$$FS = (s_{ta}/s_d)$$
$$FS = (2600 \text{ psi}/146 \text{ psi}) - 1 = 16.8$$

The analytical analysis is used for preliminary review and to determine any areas that may develop highly localized stresses. Due to the nature of polyethylene and its ability to relieve some of the stressed areas, BRH considers the prototype test program of major importance in determining the container's structural stability.

The chemical and radiological stability of cross-linked polyethylene has been tested enough to ensure, with reasonable confidence, the adequacy of this material for use in HICs.

CONCLUSIONS

Cross-linked polyethylene has many properties which are favorable for use in nigh integrity containment in the radiological waste field.

1. Polyethylene has been shown to have good resistance to degradation by many chemicals. Any chemicals which would have a detrimental affect on polyethylene are excluded by employing strict regulatory guidelines at nuclear facilities and at the low-level rad waste disposal facility in Barnwell. Therefore, it is determined that detrimental affects by chemical action will be minute, if existing at all.

2. Polyethylene has also been shown to have favorable mechanical strength for burial load support. It has the ability to relieve areas of stress by relaxation or creep. This enables the material to survive longer periods of stress while still maintaining good strength qualities. BRH does not feel that the conditions exist to develop stress cracking as indicated by the positive safety factors in all of the stress calculations.

3. All high integrity containers must meet guidelines established by BRH and the Nuclear Regulatory Commission. These guides include axial compression tests to at least 21 psi. Due to the nature of polyethylene, an analytical analysis alone is not adequate for justification or denial of a container design, thus the compression tests are considered a valuable part of their qualification. At present, BRH feels this testing adequately predicts the ability of the HICs to withstand the burial loads encountered at the Barnwell facility.

4. Extrapolations of rather large magnitudes are not unique to polyethylene. It is granted that the larger the time period for the extrapolation, the greater the possibility for error exists. However, as previously stated in BRH's response, a linear graph may not be entirely valid in determining the allowable stress at the 300 year point. The strength of polymers has a tendency to level off after a period of time. This is indicated by a leveling off of the modulus of elasticity versus time curve as shown in reference 3, figure 10.3.

Until substantial proof can be offered, BRH feels that cross-linked polyethylene is a satisfactory material for use in high integrity containers.

VARIABLES

A_t = area of the container top; in^2
A_w = area of wall cross section; in^2
B = footing width; ft.
d_o = outside diameter; in.
F_t = total force on container; lbs.
FS = factor of saftey
h_c = container height; in.
h_s = height of soil overburden; ft.
P = pressure; lbs/in^2
q = distributed load; lbs/in^2
q_w = unit load transmitted through wall; lbs/in^2
R_2 = radius of curvature; in.
R_o = outside radius; in.
s_{cr} = critical buckling stress in wall; lbs/in^2
s_{ct} = compressive stress in top; lbs/in^2
s_{cw} = compressive stress in wall; lbs/in^2
s_d = diaphragm stress in bottom; lbs/in^2
s_h = hoop stress in wall; lbs/in^2
t_b = thickness of bottom; in.
t_t = thickness of top; in.
t_w = thickness of wall; in.
y = deflection or deformation; in.

CONSTANTS

E = modulus of elasticity = 100,000 lbs/in^2

k_4 = 0.965

K_{vi} = soil compression factor = 235 $tons/ft^3$

π = pi = 3.1417

p_p = density of polyethylene = 58.2 lbs/ft^3

p_s = soil density = 120 lbs/ft^3

s_{ca} = compressive strength => 1500 lbs/in^2

s_{sa} = shear strength = 3700 lbs/in^2

s_{ta} = ultimate tensile strength @ 2 in/min = 2600 lbs/in^2

v = poisson's ratio = 0.45

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4. Soil Mechanics Design Manual, NAVFAC DM-7.1, Department of the Navy, Naval Facilities Engineering Command, May 1982.

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6. "An Assessment of Polyethylene as a Material for Use In High Integrity Containers", Engineering Design and Testing Corporation,Columbia,South Carolina, July 21, 1986,File No. 828-660.010.

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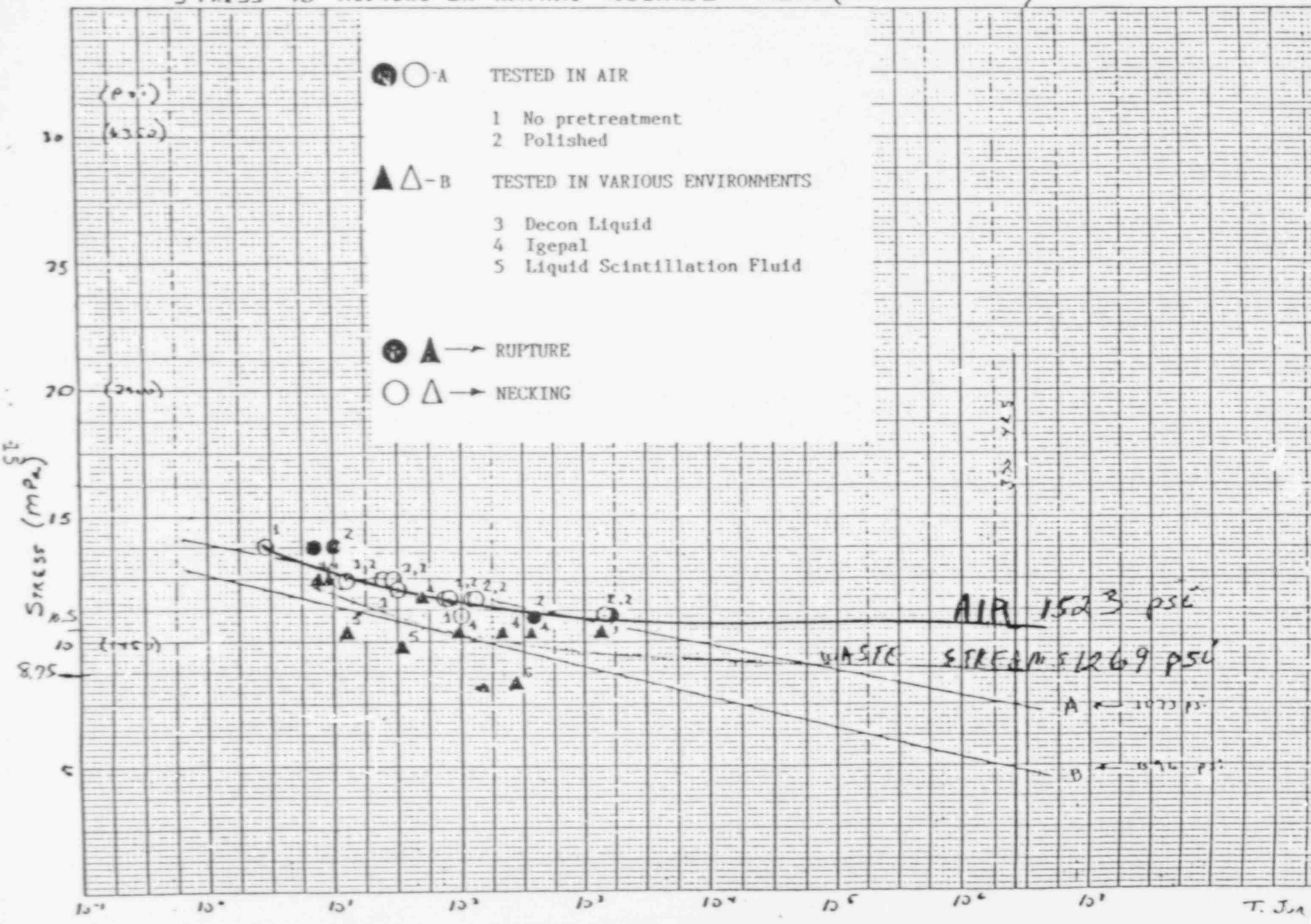
STRESS TO RUPTURE OR INITIATE NECKING - HDPE (UNIRRADIATED)



APPENDIX

ENGINEERING DESIGN & TESTING Corp.
ENGINEERS / CONSULTANTS / LABORATORIES

POST OFFICE BOX 8027 / COLUMBIA, S.C. 29202 / TELEPHONE (803) 791-8800

July 28, 1986

Mr. Steve McCoy
NUS Process Services Corp.
1501 Key Road
Columbia, SC 29201

REFERENCE: Preparation of Report on Polyethylene as a HIC Material: Related Activity
NUS-PSC Purchase Order No: 4833
ED&T File Number 828-660.010

Dear Mr. McCoy:

Enclosed is our report concerning polyethylene as a material for application in high integrity containers. As you are already aware, the basic findings of the report are that (1) polyethylene is inappropriate for use in a HIC where there is a structural requirement; and (2) existing polyethylene HIC designs on the market today do not meet published criteria.

We appreciate the opportunity to have been of service to you in conducting this review. Should you have any questions regarding the contents of the report or regarding our work in general, please feel free to give me a call at your convenience.

Sincerely,

Tim A. Jur, Ph.D., P.E.

TAJ:amh

Enclosure

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