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September 19, 1986

TMI-2 Cleanup Project Directorate
Attn: Dr. W. D. Travers
Director
US Nuclear Regulatory Commission
c/o Three Mile Island Nuclear Station
Middletown, PA 17057

Dear Dr. Travers:

Three Mile Island Nuclear Station, Unit 2 (TMI-2)
Operating License No. DPR-73
Docket No. 50-320
Core Bore Operations

The purpose of this letter is to request NRC approval of the GPU Nuclear proposal to reinstall the core boring machine over the Reactor Vessel (RV) to perform additional drilling operations into the core region to facilitate defueling. The drilling operations will be performed on the corium monolith in the core region above the lower Core Support Assembly (CSA). The drill will be administratively controlled by procedure to avoid the lower end fittings (for protection of the drill bit) and physically controlled by drill string length to prevent the drill from encountering the lower flow distributor. In general, safety considerations associated with this proposed activity are bounded by the analysis presented in Reference 1. However, in order for this operation to be effective, it is necessary to be able to drill into the corium monolith at any location within the available drilling diameter of the core boring machine without being restricted by incore instrument locations. Previous discussions on this subject raised concerns that the core boring drill could impart downward forces onto an incore instrument without cutting it. The incore instrument could then, after buckling, impart a horizontal force to the top of the incore nozzle. This horizontal force could cause a bending moment to develop at the incore nozzle weld. It was postulated that this moment would exceed the recommended moment limit of 1400 in-lb developed in Reference 2.

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Recent examinations of the TMI-2 core and support structure afforded by the Lower Head Core Stratification (Core Bore) Program have provided further insight into the condition of the lower CSA, the incore instrument nozzles and the RV lower head. In general, little damage was evident. Based on these observations, GPU Nuclear requested B&W to review the RV lower head structural integrity analysis presented in Reference 2. Based on a review of the video coverage of the Core Bore Program, along with environmental and metallurgical considerations, B&W reassessed the structural integrity of the RV lower head, particularly the Inconel 600 weld between the incore nozzle and the RV lower head. These new findings are addressed in the attached B&W report entitled, "TMI-2 Incore Nozzle Evaluation," dated September 15, 1986 (Reference 3).

Based on the evaluations presented in Reference 3, it is reasonable to conclude that the Inconel 600 welds are not degraded and have maintained their original metallurgical properties. The structural analysis demonstrates that the load carrying capabilities of an Inconel 600 weld with its original metallurgical properties would be, after applying a safety factor of two (2): 113,500 pounds in tension, 51,500 in-lbs in bending and 48,500 in-lbs in torsion. Using these allowable load limits, it can be shown that any axial or horizontal load imparted by an incore assembly cannot damage the incore nozzle weld.

Tests performed have shown that an incore instrument string will fail in tension and physically separate when pulled axially at approximately 4000 pounds. This represents the ultimate strength of the incore instrument. The yield strength of the incore in compression would be less than this figure; therefore, the maximum axial load an incore instrument could support cannot exceed 4000 pounds. The calculated axial load needed to buckle an incore instrument string in the space between the incore guide tube and incore nozzle is approximately 600 to 900 pounds. The unsupported length in this location is approximately 9 inches. As the load on the incore instrument increases after buckling, the mid-span of the buckled column would come to rest against the side of the incore instrument guide tube, imparting a horizontal load on the incore nozzle. By applying a downward force from the Core Boring Machine of 4000 pounds (i.e., the maximum axial load before the incore instrument fails in compression) the buckled incore instrument would impart a 1900 pound horizontal load to the top of the incore nozzle. The allowable bending moment of the B&W report is 51,500 in-lb which corresponds to a 4292 pound horizontal force applied at the top of the nozzle. In summary, the maximum horizontal load that can be applied to the top of the nozzle, (1900 lbs), is less than the recommended limit (4292 lbs). Therefore, the maximum axial loads which could be imparted to the incore instrument cannot overload the incore nozzle.

The above evaluation is relevant only if the incore instruments are intact. As indicated in Reference 2, it was originally calculated that the nozzle weld area of the incore nozzles reached temperatures of 2055°F to 2167°F. At this temperature, the remaining nozzle above the weld would have been between 3220°F to 4096°F. The temperature difference is due to the large heat sink provided by the RV wall. Thus, in order for an Inconel 600 nozzle weld to reach a temperature near its melting point (2540ºF), the incore nozzle and instrument string would have to have melted. Therefore, a bending moment could not be transmitted through an incore nozzle to a degraded weld. In other words, if the weld is degraded, there is no incore instrument string above the nozzle to which loads can be applied. Similarly, if the incore nozzle is intact, the nozzle weld can accept loads similar to the original design basis.

Based on the above discussions, a failure of an incore nozzle weld due to the core boring of the corium monolith is highly unlikely. However, the capabilities do exist to mitigate the consequences of an incore nozzle weld failure and the resultant leakage. As demonstrated in Reference 4, sufficient capability exists to maintain the TMI-2 core covered with borated water for an indefinite period in the event of a complete loss of an incore instrument nozzle which would result in a 125 gallon per minute leak.

In conclusion, the loads imparted to an incore nozzle weld will remain below those minimum loads calculated to be necessary to cause a failure of an incore nozzle weld that exhibits original metallurgical properties. However, if a weld is degraded, it is expected that the remaining incore nozzle would have melted. In addition, the consequences of the failure of an incore nozzle have been previously evaluated. Therefore, this proposed activity does not represent an unreviewed safety question since it does not create consequences or increase the probability of an accident previously evaluated, create the possibility of an accident of a different type than previously evaluated, or reduce the margin of safety as defined in the Technical Specifications. Thus, the proposed activity can be performed without undue risk to the health and safety of the public.

Per the requirements of 10 CFR 170, an application fee of $150.00 is enclosed.

Sincerely,

Thomas J. Dernell
for F. R. Standerfer
Vice President/Director, TMI-2

FRS/CJD/eml

Attachment

Enclosed: GPU Nuclear Corp. Check No. 00025904

REFERENCES

1. Core Stratification Sample Acquisition Safety Evaluation Report, Revision 4, GPU Nuclear letter 4410-86-L-0101 dated June 11, 1986.

2. Evaluation of the Structural Integrity of the TMI-2 Reactor Vessel Lower Head Final Report, June 1985, B&W 77-1154826-00.

3. TMI-2 Incore Nozzle Evaluation, September 15, 1986, B&W 51-1165539-00.

4. Extended Core Stratification Sample Acquisition Activity, GPU Nuclear letter 4410-86-L-0122 dated July 11, 1986.

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ENGINEERING INFORMATION RECORD

Safety Related: Yes ☒ No ☐

Document Identifier 51 -1165539-00

Title TMI-2 Incore Nozzle Evaluation

Prepared by G. J. Vames *GJ Vames* Date September 12, 1986

Reviewed by T. W. Elvin *TW Elvin* Date September 15, 1986

Adm

Remarks:

Purpose and Summary:

The purpose of this document is to present the results of an evaluation of the load carrying capability of an incore nozzle. The basis for the evaluation is that the recently reported data and observations made during the core bore program are typical of the conditions in the lower head of the TMI-2 reactor vessel. Based on our review of the videotapes of the core bore program, environmental and metallurgical observations, calculations and engineering judgement it is concluded that virgin material properties can be used for determining the strength of the incore nozzle welds because it is highly unlikely that the temperature of these welds exceeded 1200°F.

However, since it is not possible to examine the welds, it is recommended that some factor of safety be applied to the calculated strength to obtain permissible loads. Babcock & Wilcox recommends a factor to two.

Table of Contents

1. Introduction

An evaluation of the structural integrity of the TMI-2 reactor vessel lower head was performed by B&W in June, 1985. At that time video examination had revealed that a void existed in the upper region of the original core which encompassed approximately one-third of the total core volume and extended to the outermost, partially damaged fuel elements. A debris bed approximately three feet thick lay in the bottom of the lower reactor vessel head. Efforts to probe through the debris indicated that a layer of hard, impenetrable material lay beneath the surface at about mid-core elevation. Video scans of the lower region indicated that ten to twenty percent of the core material collected in the lower head. It was thought that this material flowed to the bottom of the reactor vessel while it was in a molten condition and that a "chimney" was formed in the center of the core.

From the data available at that time, the B&W study indicated that the corium formed by the fuel in the bottom head reached temperatures in the range of 4000-5000F, and that the inner surfaces of the reactor vessel head (cladding) reached temperatures in the range of 2100 - 2400F which is below the melting temperature of 2760F for the stainless steel cladding and the melting temperature of 2450F for the Inconel weld metal for the in-core instrument nozzle. Some of the in-core nozzles were sticking up into the corium and it was judged that they probably melted in that area.

Since the observations were made last year, additional information has been obtained. Holes have been drilled down through several of the fuel elements. Video scans of the drilled holes show that the lower portions of the fuel elements are still intact, ranging in lengths from 11 to 48 inches with the former being located near the center of the core. No "chimney" or void space has been located, although it could conceivably be located at some place that has not been drilled yet. The video scans indicated that the lower end fittings and bolting for the fuel elements are still intact. The scans also indicated that the material in the region just below the fuel elements (e.g., lower flow distributor) did not suffer any noticeable damage. However, no views are available for the regions near the in-core instrument nozzle welds.

In order to take advantage of this new information, a second study was conducted by B&W and documented in this report. The latest information and video tapes from the site were reviewed and a new assessment of the structural integrity of the lower head was performed. Thermal, environmental, and metallurgical conditions were considered in the evaluation. The resulting conclusions and recommendations are presented in Section 6 herein.

2. Temperature Evaluation

A review of the original temperature calculations (Reference 1), recent inspection results (References 2 and 3), and the latest video inspection results was performed in order to refine the lower head temperature estimate. Based on this review, it is likely that the temperature of the incore nozzle welds in the reactor vessel lower head did not exceed 1200 degrees F and probably did not exceed 900 degrees F. The following observations were made in making this judgement:

A. The calculation performed in Reference 1 were performed before much was known about the conditions in the lower head. Thus these calculations had to be very conservative. Specific conservatisms were:

1. All fissions products were included in the heat source term.
2. The theoretical density for a UO_2 zircalloy and inconel mixture of 8.95 was used. The average of seven measurements reported in Reference 2 was 6.86 gm/cubic-cm.
3. The geometry was assumed axisymmetric around a guide tube nozzle and was insulated at the top which was seven inches from the vessel head.
4. The thickness of the corium ring around the guide tube nozzle was four inches.

B. Even though the calculations were very conservative, they showed the essential physics of the problem, which are:

1. The stored energy is more important than the decay heat in determining the maximum temperature (assuming initial temperatures in the corium of 5000 degrees F).
2. The vessel acts as a very large heat sink or "chill block."

C. None of the instrument guide tube nozzles showed any sign of damage; thus the guide tube nozzle had to be below its melting point (about 2900 degrees F). The calculations performed in Reference 1 predicted temperatures as high as 4100 degrees F.

D. The only damage observed was to one incore instrument guide tube where a portion of the lower section which is only 1/4 inch thick had melted. A simple finite difference simulation of hot corium striking the guide tube was performed. It indicated that the 1/4 inch thick section would melt in less than a minute, while the thicker section did not melt in the ten minute simulation. This indicates that, for the most part, the corium that fell through the six inch diameter holes in the elliptical flow distributor plate did not drift over to the incore guide tube and by extension to the incore nozzles. Thus; it is highly unlikely that a monolithic ring of corium surrounds the incore guide tube nozzle as was assumed in the analysis. A nonsymmetric analysis where monolithic corium was only present on one side of the nozzle would show much lower temperatures because of the heat sink capabilities of the vessel.

E. The largest piece of recovered corium has a volume of about 15 cubic inches and most of the recovered pieces have volumes of two cubic inches and less. This must be contrasted to the 176 cubic inch volume which was used in the original analysis. Again, much smaller volumes of monolithic corium will lead to much lower maximum temperatures.

3. Environmental Considerations

B&W has made many evaluations related to the environmental (chemistry) effects of the RCS material of construction. The most significant ones are reported in References 4, 5, 6, and 7. These references cover the period from the start of the incident on March 29, 1979 through February, 1986. Subsequently, hydrogen peroxide was used in the reactor coolant to destroy bacteriological growths.

During the incident itself the RCS temperature, pressure, and water inventory went through wide ranges of conditions that made it difficult to provide a proper assessment of the chemistry environment. However, as soon as conditions had stabilized, a basic pH water environment was established by the addition of sodium hydroxide during the drawdown of the borated water storage tank. A basic pH (>7.5 at 77F) has been maintained, as pH is one parameter that can be controlled through the addition of sodium in the form of sodium hydroxide.

A basic pH is a key item in reducing the susceptibility of both austenitic stainless steels and high nickel alloys to stress corrosion cracking. Thus, with a basic pH in the RCS, the possibility of stress corrosion cracking has been reduced or minimized.

Inconel 600 is susceptible to stress corrosion cracking when reduced forms of sulfur are present. During recent periods when hydrogen peroxide was used as a biocide, a strongly oxidizing environment existed which would help oxidize the reduced sulfur species to sulfate, the only oxidized specie of sulfur that can exist. Sulfate has a low potential of being involved in any stress corrosion cracking phenomenon. Thus, it can be stated that the presence of hydrogen peroxide can be helpful in reducing stress corrosion of high nickel alloys if reduced sulfur species are present.

Based on this evaluation it appears that no environmental conditions detrimental to stainless or high nickel steel have existed in the TMI-2 reactor vessel since the incident on March 29, 1979.

4. Metallurgical Considerations

As stated in Section 2 above, the reactor vessel lower head and incore nozzle temperature likely did not exceed 1200°F at any time. This is consistent with the video tapes which show little or no damage to the fuel assembly lower end fittings and lower core support assembly. While the incore nozzle welds to the lower reactor vessel were not visible in the video tapes, it is not likely that they sustained higher temperatures than the lower core support assembly since the debris would have cooled as it fell from the core and since the lower head acts as a heat sink as described in Section 2.

Based on these considerations, in addition to the conclusions in the previous sections, the Inconel 600 weld between the incore nozzles and the lower head can be expected to have its original metallurgical properties.

5. Estimated Nozzle Strength

The analyses presented herein and in Reference 1 indicate that the critical component in the reactor vessel lower head is the incore nozzle weld. Therefore, only this weld is analyzed. During the remaining defueling program loads could be hypothetically applied to the incore nozzles by the core bore machine, the impact chisel, by load drop or other accidents. Therefore, the load carrying ability of the nozzles should be known.

The ultimate strengths of a nozzle separately in extension, bending and torsion are calculated in Reference 8. The minimum ultimate strength of Inconel 600 of 80,000 psi was used as indicated by the evaluation in the preceding sections of this report. This minimum strength is applicable from room temperature to 1000 degrees F. The nozzle was treated as a twelve inch long cylinder with a two inch outer diameter and a 5/8 inch inner diameter. This cylinder was cantilevered up from the lower head and loaded at the top. The ultimate bending and torsional loads were calculated using conservative moduli of rupture for alloy steels.

The results of the analysis show that this configuration can separately withstand 227,000 pounds in tension, 103,000 in-lbs in bending and 97,000 in-lbs in torsion.

6. Conclusions and Recommendations

Based on the assumption that the recently reported data is typical of the conditions in the TMI-2 reactor vessel lower head, it appears that (1) the incore nozzle weld temperature did not exceed 1200 degrees F; (2) there were no detrimental environmental effects; and (3) the weld metal maintained its virgin strength.

As a factor of safety it is recommended that a load of no more than one-half of the calculated strength shown in Section 5, be applied to a nozzle.

7. References

1. B&W Document 77-1149209-00, Evaluation of the Structural Integrity of the TMI-2 Reactor Vessel Lower Head, dated June, 1985.
2. TMI Technical Bulletin TB 85-21, Revision 3, dated May 9, 1986.
3. TMI Technical Bulletin TB 85-35, Revision 2, dated July 29, 1986.
4. B&W Report BAW-1629, TMI-2 RCS Component Evaluation - Task 27, dated May 1980.
5. B&W Document 86-1137540-00, Chemistry Specification Evaluation for Reactor Coolant System Cleanup, dated April, 1982.
6. B&W Document 51-1159985-00, TMI-2 pH Reduction Study, dated February, 1986.
7. B&W Document TRG-79-11, TMI-2 Recovery Project B&W Water Chemistry Manual, dated October, 1979.
8. B&W Calculation 32-1165525-00, TMI-2 Incore Nozzle Strength, dated August 8, 1986.

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DOCUMENT SUMMARY SHEET

DOCUMENT IDENTIFIER 32-1165525-00

TITLE TMI-2 Incore Nozzle Strength

PREPARED BY:		REVIEWED BY:	
NAME G. J. Vames		NAME T. W. Elvin	
SIGNATURE G J Vames		SIGNATURE TW Elvin	
TITLE Advisory Engr.	DATE 8-25-86	TITLE Prin. Engr.	DATE 8-26-86
COST CENTER 310	REF. PAGE(S) 3	TM STATEMENT: REVIEWER INDEPENDENCE ADM	

PURPOSE AND SUMMARY OF RESULTS:

The purpose of this document is to determine the strength of an incore nozzle for various wall thickness.

The results are shown on Page 4.

THE FOLLOWING COMPUTER CODES HAVE BEEN USED IN THIS DOCUMENT

CODE / VERSION / REV	CODE / VERSION / REV
NONE	

1. Introduction

The purpose of this document is to determine the load carrying capability of the TMI-2 Incore Instrument Nozzles in the lower head of the reactor vessel. The loads required to separately fail a nozzle in tension, bending, or torsion are calculated assuming virgin material properties. Loads are calculated for various tube thickness.

2. Method of Analysis

The geometry and material properties used in Reference 1 are used in this analysis. The virgin nozzle is considered as a twelve inch long tube with a two inch OD and a 5/8 inch ID. Strengths are calculated for various wall thicknesses up to that of the virgin tube. The material is Inconel 600 with a minimum ultimate strength of 80,000 psi from room temperature up to 1000 ^{o}F.

The moduli of rupture in bending and torsion from Reference 2 are used in determining the ultimate strengths. It is assumed that the ID remains constant and that the wall is thinned from the outside since this gives the lowest strength for a given thickness.

3. Analysis

The strengths of a nozzle separately in tension, bending, or torsion are calculated in Table 1. The results are shown graphically in Figure 1.

The moduli of rupture in bending and torsion, MR_b and MR_t, were taken from Figures 2.7.1.1 and 2.7.3.2 (b) respectively of Reference 2. These values are for alloy steel and therefore are conservative for Inconel which exhibits more strain hardening than alloy steel. The moduli are calculated as shown in the following example.

@ t = .125 in., Davg/t = 6.00

F_b = 129,000 psi (elastic failure bending stress for 90,000 psi steel)

MR_b = 129,000/90,000 = 1.43

The modulus of rupture is then multiplied by the 80,000 psi tensile strength of Inconel 600 to determine the equivalent strength to be used in the elastic equations.

$P = (S_u)(A)$	Axial
$M = (MR_b)(S_u)(I)/(OD/2)$	Bending
$T = (MR_t)(S_u)(J)/(OD/2)$	Torsion

4. References

1. B&W Calculation 32-1157102-01, Max. Incore Nozzle Loads, dated 5-30-85.
2. MIL - HDBK - 5B, Metallic Materials and Elements for Aerospace Vehicle Structures, dated 9-1-71.

t-in.	ID-in.	OD-in.	Davg-in.	A-in*2	I-in*4	J-in*4
0.0625	0.625	0.750	0.6875	0.13499	0.00804	0.01608
0.1250	0.625	0.875	0.7500	0.29452	0.02128	0.04257
0.1875	0.625	1.000	0.8125	0.47860	0.04160	0.08319
0.2500	0.625	1.125	0.8750	0.68722	0.07114	0.14228
0.3125	0.625	1.250	0.9375	0.92039	0.11235	0.22470
0.3750	0.625	1.375	1.0000	1.17810	0.16797	0.33594
0.4375	0.625	1.500	1.0625	1.46035	0.24101	0.48203
0.5000	0.625	1.625	1.1250	1.76715	0.33479	0.66958
0.5625	0.625	1.750	1.1875	2.09849	0.45290	0.90579
0.6250	0.625	1.875	1.2500	2.45437	0.59921	1.19842
0.6875	0.625	2.000	1.3125	2.83480	0.77791	1.55582

t-in.	Davg/t	L/Davg	MRb	MRt	P-lbs	M-in lbs	T-in lbs
0.0625	11.00	17.45	1.29	0.58	10799	2213	1990
0.1250	6.00	16.00	1.43	0.63	23562	5565	4904
0.1875	4.33	14.77	1.52	0.66	38288	10116	8785
0.2500	3.50	13.71	1.58	0.76	54978	15986	15379
0.3125	3.00	12.80	1.59	0.77	73631	22866	22147
0.3750	2.67	12.00	1.60	0.78	94248	31273	30491
0.4375	2.43	11.29	1.61	0.78	116828	41390	40105
0.5000	2.25	10.67	1.62	0.78	141372	53402	51424
0.5625	2.11	10.11	1.63	0.78	167879	67494	64596
0.6250	2.00	9.60	1.64	0.78	196350	83858	79767
0.6875	1.91	9.14	1.65	0.78	226794	102684	97083

NOTE: (1) Su = 80,000 psi
(2) L = 12 inches

Table 1

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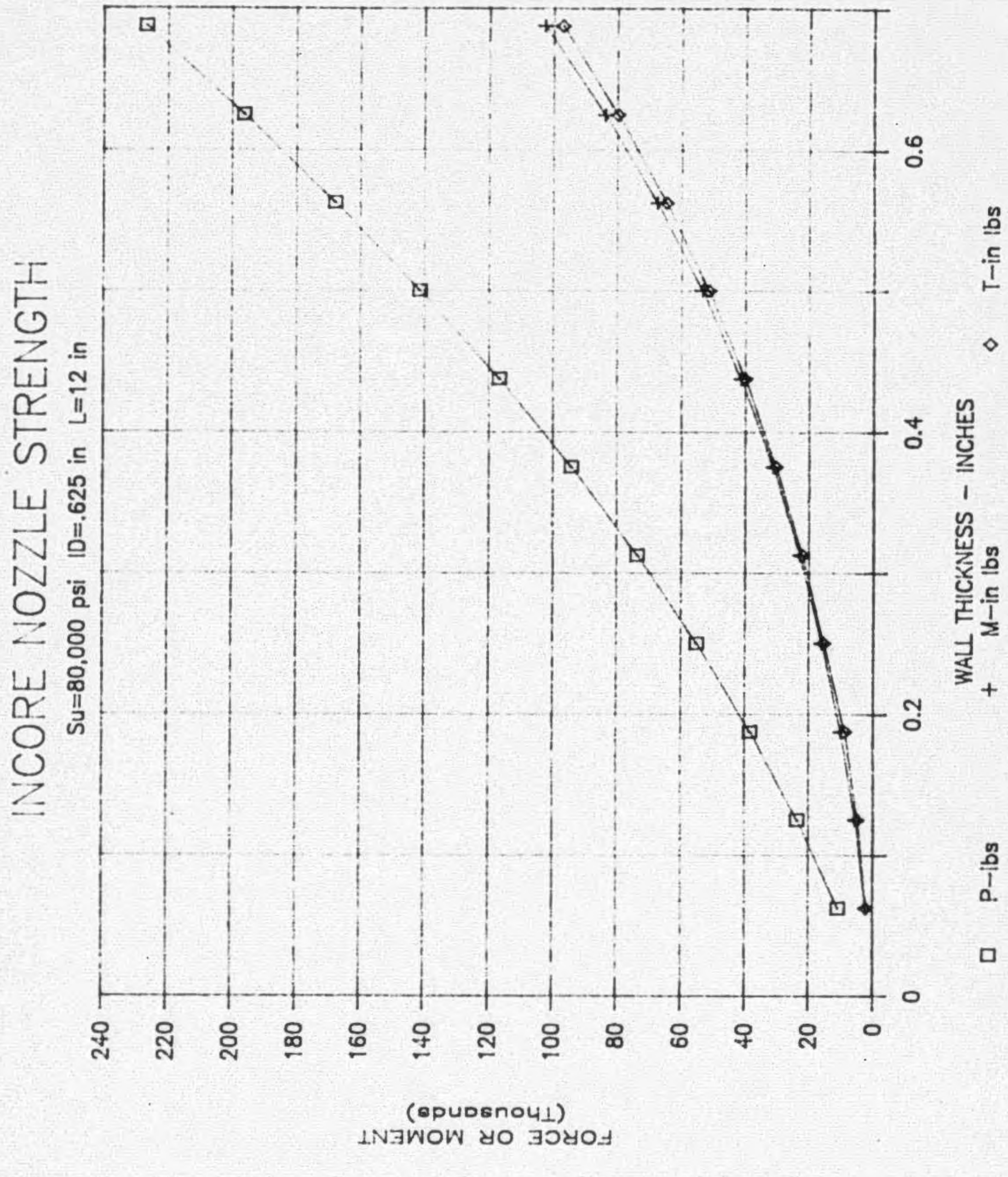
DOC. I.D. 32-1165525-00

Figure 1



PREPARED BY 8 [signature] DATE 8-25-86

REVIEWED BY TW Elvin DATE 9-86