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SUMMARY REPORT OF REINSPECTION AND APPRAISAL OF THE INDIAN POINT NO. 3 REACTOR PRESSURE VESSEL SUBSEQUENT TO HOIST FAILURE ON JANUARY 12, 1971

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Summary Report of ORNL Consulting Services to
Consolidated Edison Company of New York, Inc.
per
Consultant Contract OIC-C-45

Approved by
Wm. B. Cottrell, Director
Nuclear Safety Program

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for the
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Abstract

On January 12, 1971, the Indian Point Unit 3 reactor pressure vessel underwent an unscheduled descent during its installation. As a consequence of that incident, Oak Ridge National Laboratory was asked by Consolidated Edison to provide Technical consultation regarding the reinspection of the vessel being conducted by Westinghouse Electric Company. The reinspection involved visual and dimensional checks of the vessel, as well as non-destructive examination techniques such as dye penetrant, magnetic particle and ultrasonic. The results of these non-destructive examinations served as the basis for an assessment of possible damage to the unit based on fracture mechanics. None of the inspections revealed any indications of damage to the pressure vessel. This position was further substantiated by the fracture mechanics calculations. The ORNL consultants concluded that the vessel was not damaged as a consequence of the incident, thereby confirming a similar conclusion by Westinghouse Electric Company.

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1. INTRODUCTION AND SUMMARY

On January 12, 1971, the Indian Point Unit 3 reactor pressure vessel underwent an unscheduled descent while being hoisted during its placement in the pit in which it is to operate. At the time of the incident, the vessel was the property of the prime contractor, Westinghouse Electric Corporation, who had subcontracted the pressure vessel to Combustion Engineering. The purchaser, Consolidated Edison Company of New York, Incorporated (Con Ed), obtained the consultation services of the Oak Ridge National Laboratory (ORNL).

The consultation services requested of ORNL as described in Consolidated Edison's letter to Dr. H. M. Roth of the AEC dated February 2, 1971, were:

1. Review of the details of the analysis and inspection programs planned by Westinghouse and Combustion Engineering so as to advise Con Ed as to their sufficiency or to suggest needed additional inspection or analyses.

2. To follow up on the inspections themselves to determine the adequacy of performance or suggested desired adjustments and their performance and, if it appears required, make recommendations to Con Ed regarding additional inspections or tests.

3. Review the data and the analysis performed under Westinghouse-Combustion Engineering program and advise Con Ed as to their opinion of the conclusion made by Westinghouse and Combustion Engineering concerning the integrity of the vessel.

4. Prepare a final report which includes all the observations and activities performed by ORNL and their conclusions.

A three-man ORNL task force was established to undertake the designated work. The ORNL task force first visited the Indian Point site in late January before the vessel was moved following the incident.

On February 1, a copy of the reactor vessel reinspection program prepared for Westinghouse by Combustion Engineering (CE), the fabricators of the pressure vessel, was received from Con Ed. The program was reviewed and suggestions concerning additional inspections were prepared. At a meeting with Con Ed, Westinghouse, and CE on March 2, 1971, in Chattanooga, Tennessee, changes were made in the proposed CE reinspection program, most noteworthy of which was the addition of the ultrasonic inspection technique.

The reinspection of the reactor vessel was done on March 10 through March 12 at the Indian Point site by personnel from the CE plant in Chattanooga with ORNL personnel present. Following that inspection, ORNL personnel commented on their concern regarding certain aspects of the magnetic particle and ultrasonic examinations.

ORNL personnel conclude that a 2-in. flaw size could not have gone undetected in the inspected areas. This information facilitated an assessment of the effects on the reactor vessel, based on stress analysis and fracture mechanics. It concluded that flaws of less than 2 in. would not have been extended as a consequence of the incident.

ORNL's comments regarding the inspection were discussed in a meeting between the interested parties at CE in Chattanooga on April 23, 1971, and a second reinspection to cover the ultrasonic and magnetic particle tests was scheduled. The reinspection was done satisfactorily on April 29 through May 1.

The ORNL task force concluded that no damage was done to the Indian Point Unit 3 reactor pressure vessel as a result of the January 12, 1971, incident. This is based on both the results of the inspections, which were observed and substantiated by ORNL personnel, as well as by the analysis based on fracture mechanics.

In addition, the ORNL task force reviewed the report of the Handling Incident Investigation for the Indian Point Unit No. 3 Reactor Vessel submitted to Con Ed by Westinghouse Electric Corporation. Westinghouse concluded that the vessel was not damaged as a result of the incident, with which we agreed. However, we take exception to some comments concerning the nondestructive examination and their remarks regarding the stress analysis.

A summary of the findings of the ORNL task force is presented in this report.

2. DESCRIPTION OF THE INCIDENT

2.1 General

Following the arrangements for consulting services, and ORNL task force visited the power plant site, Buchanan, New York, nine days after the occurrence of the incident. Two half days, January 21 and 22, were spent inspecting the vessel and discussing the incident with Con Ed and WEDCO personnel. In addition, Con Ed gave ORNL photographs which had been taken before, during, and after the incident. Figure 1 shows the vessel and the shipping rig to which it is bolted being delivered.

2.2 Sequence of Events

Con Ed obtained information documented on the incident from interviews with a number of witnesses. The weather was clear, and the temperature was 32°F. The weight of the vessel, sled, etc., was as follows:

Reactor vessel	344 tons
Shipping rig	85 tons
Vessel cover	9 tons
Nozzle and penetration covers	3 tons
Crane hook	~15 tons

After the vessel and its skid had been moved into position near the center of the partially erected containment vessel shell, the hoist hooks were attached to the vessel rig. This attachment was made on the top end of the vessel (in its normal operating position). The top end of the vessel was then lifted while the front end of the skid rested on the floor.

During hoisting, photographs were made showing the vessel at various stages of ascent up to about an 85° angle with the horizontal . This position of the vessel and shipping sled is shown in Fig. 2. When the vessel was raised to about 85° angle, the hoist motor in the crane overheated

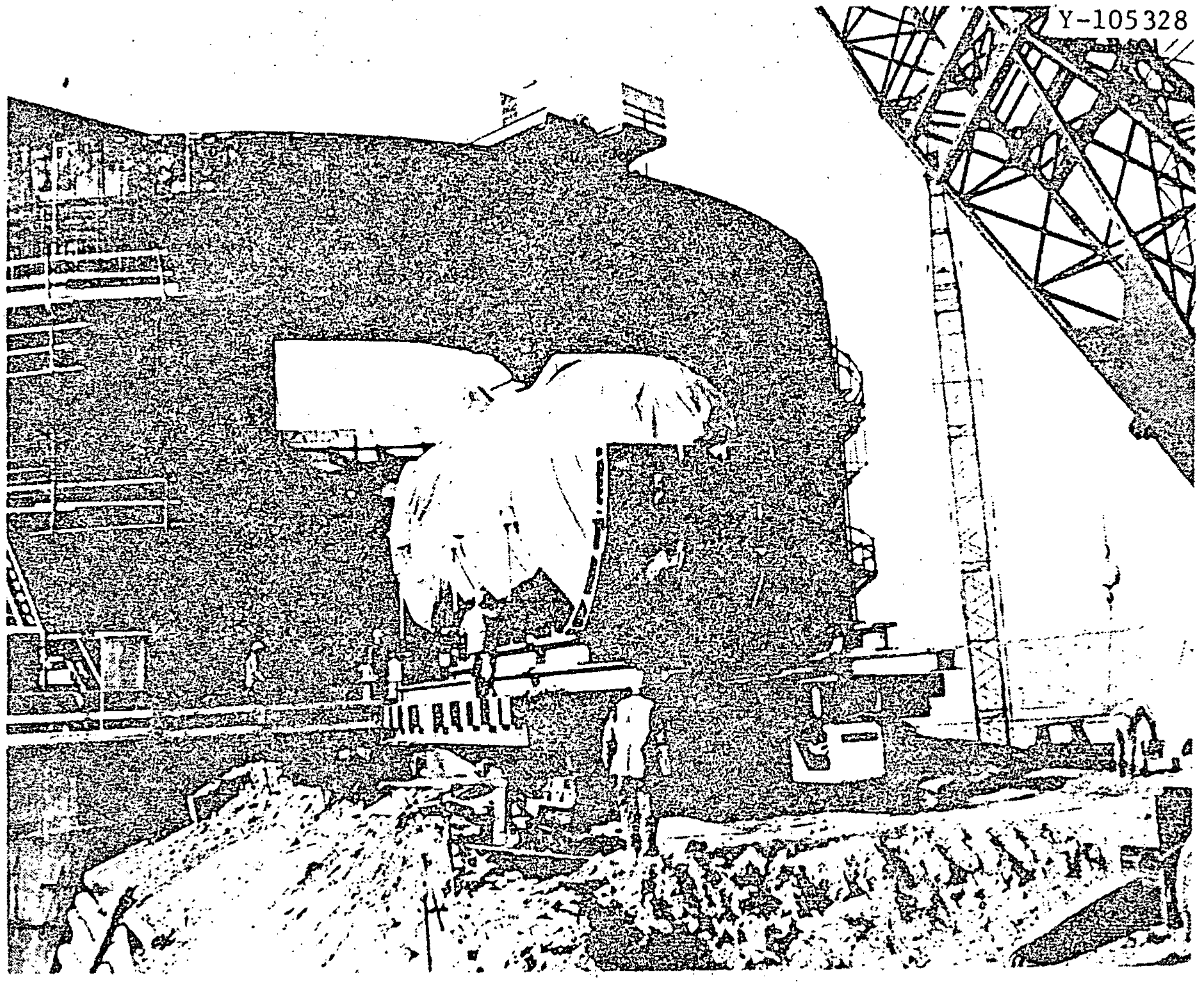

Fig. 1. Vessel Being Moved Onto Site. Note shipping ring and U-shaped hold-down bolts.

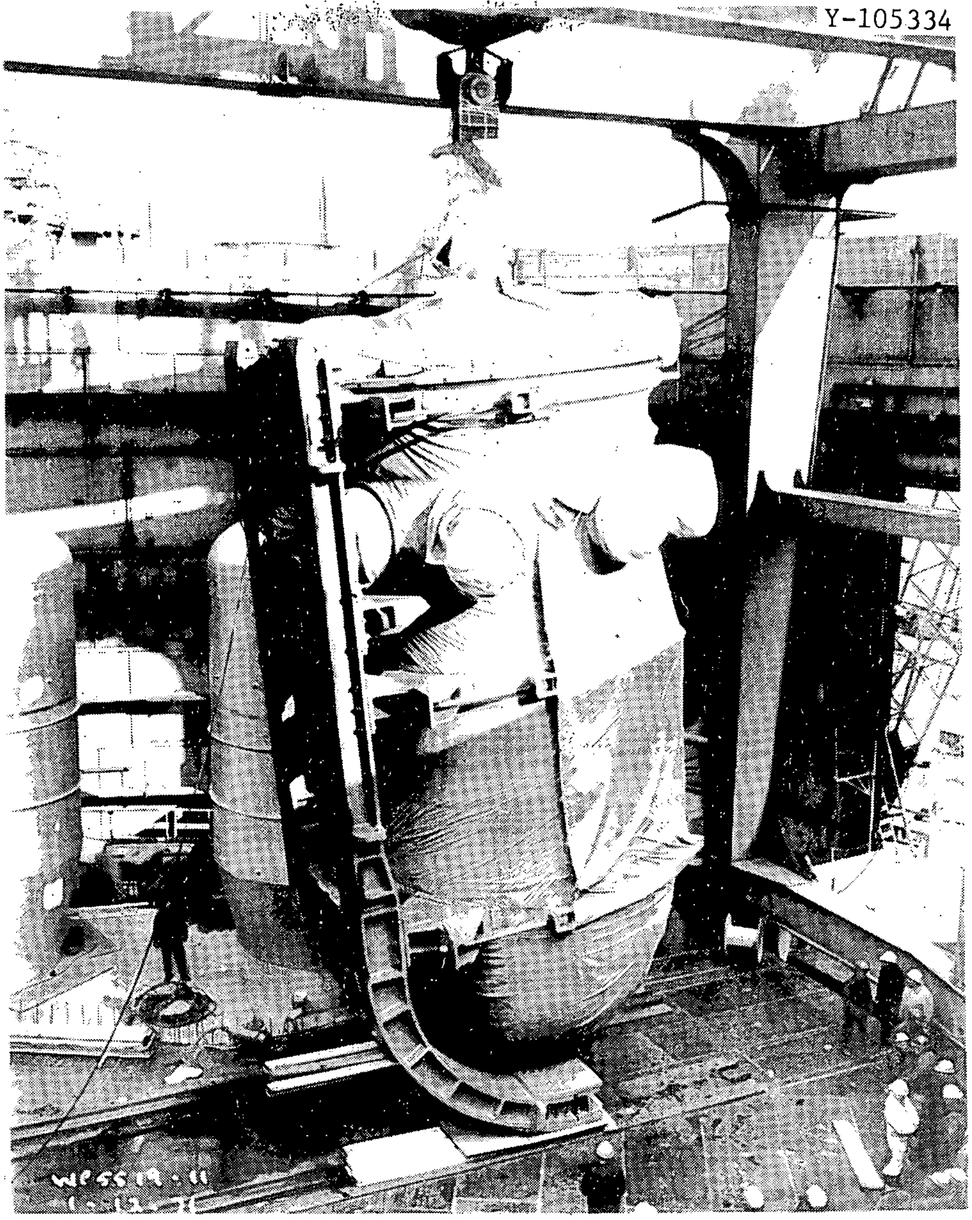

Fig. 2. Vessel and Shipping Rig at About 85° Elevation. At this position the lifting operation was halted to allow the crane motors to cool. Vessel, crane hook, shipping rig, and covers weigh about 456 tons.

and hoisting was subsequently halted. When hoisting was restarted, the vessel and its skid fell back to the horizontal position and close to their original location on the floor. The incident was caused by the failure of the hoist.

The visual inspection of the pressure vessel at this time gave no indication of any damage.

2.3 Preliminary Assessment of Evidence

Personnel gave varied descriptions of the incidents; the one aspect in which there seems to be some agreement is that the descent took from 15 to 60 sec. The vessel and shipping rig sat on temporary flooring of steel plate on 24-in.-wide flange beams.

A photograph (Fig. 3) of the plywood sheet which was under one of the "runners" of the shipping rig revealed a set of circular indentations due to the sled runners and a second set of less-distinct marks about 1 ft behind the first. This evidence indicates that the vessel may have just begun to leave the floor (at which time the crane was bearing the full load) when the crane failure occurred. This would have resulted in the slight skip backward. The vessel then realigned itself in the horizontal position. The wire ropes that were attached to the hoist (and, consequently, hoist house) dragged the operator's cabin as the vessel realigned itself. The cabin could have acted as a brake.

The vessel descended to the left of its original position. One track (channel) was flattened. The only obvious structural deformation occurred in the six 24-in.-wide flange beams buckled in the area on which the upper left portion of the vessel came to rest (Fig. 4). The deformation is in the web portion and was instrumental in permitting the estimation of stress required in the structural evaluation (Sect. 4).

Another measure of the "severity" of the descent is indicated by the tack welds that hold the deck plates together. They appear to be single-pass welds whose nil-ductility transition temperature should be higher than 30°F. These welds were not cracked. This was true of all the deck plate welds observed both near and under the vessel. The short tack welds

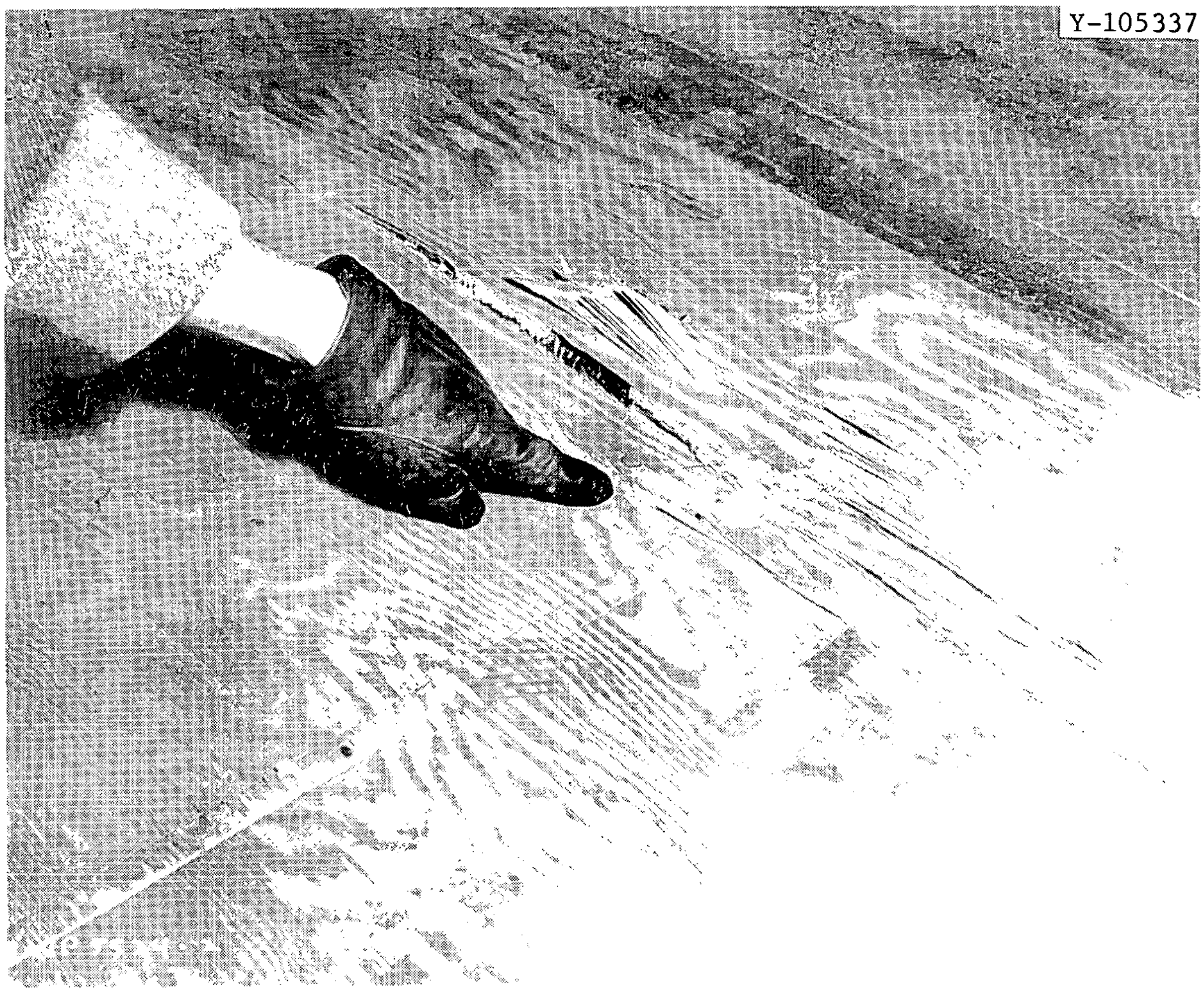

Fig. 3. Plywood That Rested Below Front "Runners" of Shipping Rig (see Fig. 2). Note circular indentations caused by bolt holes in shipping rig (see Fig. 1). Double set of indentations indicate vessel plus shipping rig was off the ground.

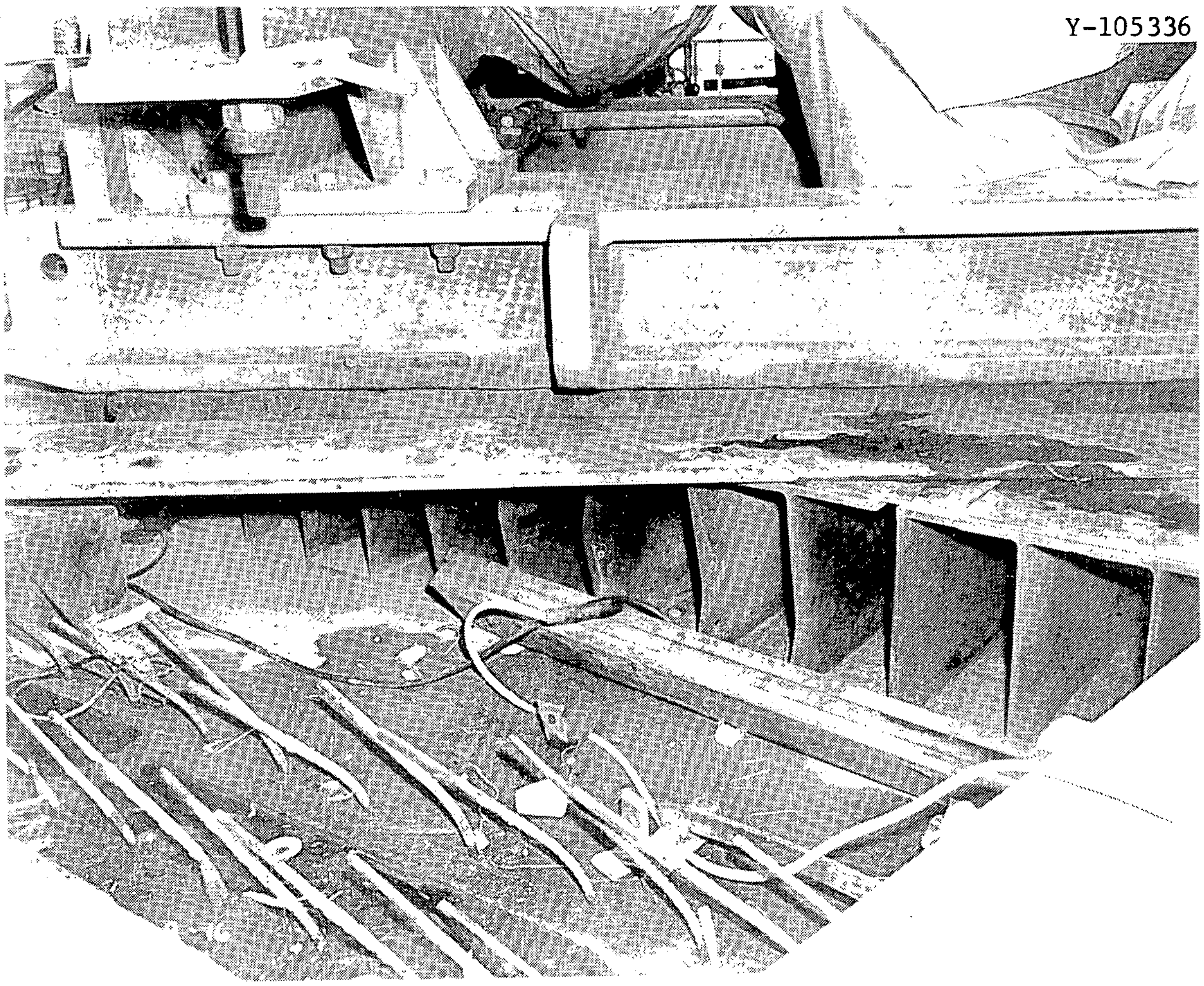

Fig. 4. Buckled Wide Flange Beams at Top Left (as viewed from bottom) of Vessel. The shipping rig "runner," 1 1/2-in.-thick plate is evident. The webs of six beams were buckled for a distance of about 5 to 6 ft. The shipping rig extended beyond the support floor at this location.

contain sharp notches. This fact combined with the presumably low toughness of a noncritical weld could result in their failure at fairly low impact loads.

Other effects that may have been a result of the fall were: (1) an indication that the hold-down U-bolts may have slipped about 1/2 to 1 in. and (2) a bolt about 1 in. in diameter that was a structural component of the shipping rig had failed in what appeared to be a brittle manner.

2.4 Relevant Pressure Vessel History

The pressure vessel was built in accordance with the ASME Boiler and Pressure Vessel Code, Section III, "Nuclear Vessel," which was in effect in April 1966. The vessel was fabricated from ASTM A302, grade B, steel and modified in accordance with CE purchase specification P3F12(a). This modification results in a steel that is essentially ASTM A533, grade B, class 1. The thickness of the vessel ranged from 8 5/8 to 10 3/4 in. excluding the approximately 1/4-in. stainless steel overlay.

The vessel was manufactured by Combustion Engineering in Chattanooga, Tennessee. It was subject to those inspection requirements in the applicable Code edition at the time of fabrication. In addition, the vessel was given an ultrasonic inspection after the hydrostatic test; and a "map" was made of the indications. This "map" was available as part of the overall information leading to conclusions regarding the integrity of the vessel. It did not contain any indications in the areas of interest to us due to the incident.

3. NONDESTRUCTIVE TESTING AND INSPECTION

3.1 The First Post-Incident Inspection

After the pressure vessel incident, Combustion Engineering proposed a program of analysis and inspection to assess the damage (if any) sustained by the vessel. The program included visual examination of the entire vessel with emphasis on the impact areas and other critical regions, dimensional inspections (primarily major diameters of the vessel), functional checks of instrument tubes and threads in stud holds, magnetic particle inspection, and penetrant examination. ORNL and Con Ed reviewed the proposed inspection program and recommended a number of changes including (1) the addition of a few dimensional measurements, (2) adding inspection areas for magnetic particle and penetrant examinations (e.g., welds in areas of maximum bending moment), and (3) adding ultrasonic examination to detect possible subsurface discontinuities, particularly in welds at regions of impact or maximum bending moment.

On March 2, 1971, representatives from Con Ed, Westinghouse, CE, and ORNL agreed on the scope of the vessel inspection (see Appendix A).

On March 10 and 11, 1971, ORNL personnel were at the Indian Point Plant to witness the inspection being performed by CE personnel. ORNL personnel considered that the visual and dimensional inspections were performed in accordance with the procedure and in an adequate manner. No evidence of damage was revealed by these examinations. The liquid penetrant examination was performed with a marginal technique, but was considered to be adequate for the intended purpose. Again, no evidence of damage was revealed. It was considered that the magnetic particle examination was inadequate due to insufficient application of powder and too short a time being used for magnetizing and observation. The ultrasonic examination was considered by ORNL to be adequate to demonstrate that the stainless steel cladding was sufficiently bonded to the base material in the areas examined, but was inadequate for the evaluation of discontinuities in the base metal and welds of the examined areas. Indications observed during the shear-wave examination were not evaluated to determine their significance, and an improper calibration was used for the longitudinal wave examination.

Subsequently, a meeting was held at the CE plant in Chattanooga on April 23, 1971, with representation from Westinghouse, CE, Con Ed, and ORNL. It was determined that the questioned ultrasonic and magentic particle examinations would be redone in a manner mutually agreeable to CE and ORNL.

3.2 The Second Post-Incident Inspection

On April 27, 1971, a meeting was held at the CE plant in Chattanooga at which the procedures to be used in the second nondestructive examination were agreed upon by representatives from CE, Westinghouse, and ORNL. A revised ultrasonic procedure was written incorporating desired features from several referenced documents. The original referenced procedures were Combustion Engineering M & D Spec. No: 2.4.4.19(b) "Specification for Ultrasonic Testing of Plate" and Shop Order V-70553 Supplement 2, "UT Testing of Base Metal" (see Appendix A). It was agreed that the two cited documents would be incorporated into a single procedure including minor points to allow a comparison with the ultrasonic test performed on the vessel after the hydro-test. The resultant ultrasonic test procedure is attached as part of Appendix B. A paragraph-by-paragraph comparison between the procedures intended for use at the first and second inspections shows only the following differences (paragraph references are to the second procedure).

1. In paragraph 5.3, a parenthetical statement has been added. "(In this paragraph, the gain of the instrument shall be increased to provide a 90% back reflection in an indication free area.)"

Comment: This involves the evaluation (and recording) of discontinuities that reduce the back reflection by 50% or more. Increasing the amplitude of the back reflection to 90% (as compared to the previously used 50-75%) would require the loss of back reflection to be greater for recording — effectively reducing the sensitivity slightly in the second inspection procedure.

2. Paragraph 5.3(a) and (b) require that discontinuities to be recorded according to paragraph 5.3 shall be recorded to show amplitude of signal in 10% increments and depth below the inspection surface.

Comment: Simple guideline for data recording.

3.* Paragraph 6.1 — Allowance was made for the use of 2.25 Mc transducer in addition to the 1.0 Mc transducer.

4.* Paragraph 6.5.1 — A calibration notch with a depth equal to 3% of the wall thickness was required for each perpendicular direction (parallel and perpendicular to the weld beads) rather than only one as before.

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*No recordable indications were noted during the shear wave inspection but for completeness in this account the changes 3 and 4 in the second procedure as noted.

5. Paragraph 7.1 — Required locating of recordable indications radially in 1/2° increments and axially within 1/16 in.

In addition, it was agreed that an air gun would be used for powder application during magnetic particle inspection.

The reexamination began on April 29, 1971. The magnetic particle examination procedure was demonstrated on site to assure the ability to detect cracks in the overhead position and to determine the proper amount of time to perform each of the required steps. The agreed-upon time was then used for each increment of the examination. No elongated indications were detected.

The ultrasonic examination was performed in accordance with the established procedure. During the examination using longitudinal waves and a 2.25 MHz transducer, eleven recordable (not rejectable) indications were noted, marked, and recorded. These were areas in which discrete indications were received from discontinuities accompanied by at least a 50% loss in back reflection. Since the procedure allowed the use of a 1 MHz transducer, each of the recordable indications were reevaluated at 1 MHz. Under those conditions, three of the previously recorded indications would not have been recordable. During the shear-wave examination, nine indications were noted with amplitudes equal to or exceeding that from the reference notch. The consistent position of the indications on the face of the cathode ray tube (corresponding to distance in the metal) raised questions about the validity of the signals. However, without further investigations, the indications were similar to those that would have been obtained from genuine flaws. Therefore, the indications could not be dismissed without further evaluation. Additional evaluation was accomplished by moving the transducer to other positions on both the inner and outer surfaces of the vessel while still directing the sound beam through the area containing the pseudo-flaw. None of the secondary evaluations produced an indication from the suspect. Therefore, the logical conclusion was that the previously observed signal was probably caused by the ultrasonic beam being changed in direction due to irregularities in the weld clad surface at the interface between the weld clad and the base metal. Special attention during shear-wave examination was also given to the areas containing the longitudinal indications. Only small, if any, indications were noted. This indicates that the discontinuities noted during the longitudinal examination had a laminar orientation.

4. STRUCTURAL AND METALLURGICAL EVALUATION

4.1 Statement of Problem

Vessel damage can be assessed through the combined considerations of nondestructive examinations, metallurgical evaluation, and fracture mechanics. An assessment of this nature can strengthen a nondestructive examination wherein a maximum undetected flaw size can be determined. This multidiscipline approach was used after the first reinspection of the Indian Point Unit 3 pressure vessel following the incident.

The fracture mechanics analysis showed that only preexisting part-through surface defects of a size too large to be missed, even by a cursory inspection, would have been extended due to the incident. This was proven both by considering the superior fracture toughness of the near surface material of the vessel wall, and by showing that the impact stresses in the vessel wall were actually quite low, a conclusion supported by all of the visual evidence.

4.2 Metallurgical Considerations

Experimental data have shown that the yield stress and the fracture toughness of the near surface material in nuclear pressure vessels are higher than for midplate material. This is due to the faster rates of cooling that occur near the surfaces during quenching and tempering.

NDT temperatures at the surfaces are as low as -150°F, as opposed to $+10^{\circ}$F, between the 1/4T and the 3/4T locations. Using these data, calculations were made to estimate the near surface fracture toughness as the average value of the static and the dynamic fracture toughnesses. These values were used in combination with the conservative assumption that the stresses reached, but did not exceed, the yield stress, to calculate that flaws smaller than 2.16 in. in depth would not have been extended during the incident.

4.3 Estimation of Loads

As estimate of the impact stresses in the vessel was made by calculating the load required to buckle the webs of the six wide-flange beams found buckled directly beneath the vessel. The calculated load was 1800 tons, which is about four times the weight of the vessel plus the skid. Assuming that this load was carried entirely by the thinnest part of the vessel, which is the cylindrical core region, the calculated maximum bending stress is 11,600 psi, which is far below the yield stress. Using this calculated stress, and assuming that the fracture toughness is the minimum dynamic fracture toughness of the midplate material, leads to a critical flaw size of 3.72 in.

4.4 Significance of the Fracture Analyses

Two types of fracture analyses, both believed to be conservative, were made for the purpose of estimating the critical size of a flaw that would have been extended by the stresses induced in the incident. In one analysis, the induced stress at the vessel surface was simply and conservatively assumed to be the yield stress, and realistic values of fracture toughness were used. The smallest flaw depth calculated by this method is 2.16 in. In the other analysis, the load on the vessel was first calculated on the basis of observed damage (and lack thereof) in supporting structures. Stresses thus determined were combined with conservative dynamic fracture toughness values with the conclusion that a flaw of depth less than 3.72 in. would not have been propagated.

The critical size of a flaw would vary according to location and orientation in the vessel, and in both analyses these values represent the smallest sizes with respect to this factor. It should also be noted that the yield stress levels assumed in the first analysis are much higher than the maximum stress calculated in the second analysis.

We conclude that since the on-site nondestructive examination revealed no flaws larger than 2 in., no existing flaws could have been extended as a consequence of the incident.

The foregoing analyses are discussed in detail in Appendix C.

5. REVIEW OF WESTINGHOUSE REPORT ON THE INCIDENT

In a letter dated October 27, 1971, Con Ed transmitted to ORNL the Westinghouse report concerning the incident at Indian Point on January 12, 1971. The report, dated July 13, 1971, and authored by Mr. R. D. Pearsall, is entitled "Handling Incident Investigation for the Indian Point Unit No. 3 Reactor Vessel." The report covers all aspects of the incident; however, our review was directed to those sections which deal with the reactor vessel.

Westinghouse Electric's observation that the vessel was not visually damaged as a result of the incident is correct. Further, we are in agreement with their conclusion that the structural integrity of the vessel was not affected by the incident. However, there are areas with which we disagree. Their position that the absence of permanent deformation and internal and external defects in the reactor vessel material establishes that the loads actually imposed on the vessel were not detrimental is unfounded. The fact that crack propagation can occur at stresses considerably below yield is well established and serves as the basis for the assessment of toughness in general and the field of fracture mechanics in particular. In addition, their implication that the second ultrasonic inspection wherein the indications were found was conducted at a higher sensitivity is incorrect. A review of the ultrasonic examination indicates if the sensitivity was affected it was effectively lowered.

6. RESULTS AND CONCLUSIONS

Oak Ridge National Laboratory personnel participated in the assessment of the integrity of the Indian Point Unit No. 3 reactor pressure vessel as a consequence of the incident on January 12, 1971. An ORNL task force was formed; this task force first visited the site at Buchanan, New York, on January 21, 1971, to visually inspect the vessel, shipping rig, and surrounding areas. Evidence of damage to the vessel was not observed. The only damage noted was moderate buckling of six 24-in.-wide flange floor beams and evidence of cable failure. The wide-flange beam damage was factored into an analytical assessment of possible vessel damage. The cables are not included in the scope of the consultation request made of ORNL.

Combustion Engineering prepared for WEDCO a proposal of the program which they suggested would permit them to assess the integrity of the vessel as a consequence of the incident. ORNL and Con Ed reviewed the proposal, and additional ultrasonic tests were included in the nondestructive investigation.

The visual, dimensional, and nondestructive examinations were conducted by Combustion Engineering under the observation of ORNL inspectors on March 10 through March 12, 1971. The ORNL inspectors were dissatisfied with the nondestructive examination techniques employed by Combustion Engineering. Although dissatisfied with the inspection *per se*, the ORNL inspectors were able to provide a maximum flaw size value of 2 in. that would not have gone undetected as a consequence of the ultrasonic examination, and this served as the basis for an analytical appraisal of the integrity of the pressure vessel. Based on the fracture toughness of the steel employed in the fabrication of the vessel (ASTM A302 B modified) at the temperature (30°F) at the time of the accident, it was shown that a flaw size of greater than 2 in. would be required to propagate a crack. Further, based on an analysis of the stresses imposed on the vessel as a consequence of the accident, the flaw sizes would have to be greater than 3.7 in. to propagate. Hence, two conservative analytical approaches employing fracture mechanics indicate no damage was done to the vessel as a consequence of the accident.

A meeting at Chattanooga on April 23, 1971, resulted in a decision that the inspection was to be repeated.

The second inspection, again under the observation of the ORNL inspectors, took place at the site on April 29 through May 1, 1971. The "agreed-upon" procedures for conducting the nondestructive examinations were properly applied to the areas of interest. This inspection produced eleven recordable indications (not rejectable) during the longitudinal wave ultrasonic test. No recordable indications were observed with the shear-wave examination.

The results of the nondestructive examination did not produce any evidence of indications that were rejectable by the established test procedures. This was also true of the visual and dimensional evaluations conducted by Combustion Engineering. These data, coupled with the results obtained from the analytical evaluations made employing fracture mechanics, indicate that the Indian Point Unit No. 3 reactor pressure vessel was not damaged as a consequence of the upending incident on January 12, 1971.

APPENDIX A — FIRST POST-INCIDENT INSPECTION PROCEDURES

A.1 — Process Specification for Magnetic Particle Examination A2

A.2 — Inspection and NDT Program for Determining the Condition of the INT/3366 Reactor Vessel Subsequent to the Site Upending Accident A9

A.3 — Process Specification for Liquid Penetrant Examination — ASME Section III A15

A.4 — Specification for Ultrasonic Testing of Plate Material A20

A.5 — UT Testing of Base Metal A23

A.1 — PROCESS SPECIFICATION FOR MAGNETIC PARTICLE EXAMINATION

COMBUSTION ENGINEERING, INC.
NUCLEAR COMPONENTS DEPARTMENT

M&P Spec. No.: 2.4.2.4(b)
Date: May 2, 1966
Sheet: 1 of 7

PROCESS SPECIFICATION FOR MAGNETIC PARTICLE EXAMINATION

1.0 Scope:

These rules describe magnetic particle examination procedures which are approved for use when magnetic particle examination is specified under Section III of the ASME Rules for Construction of Nuclear Vessels.

1.1 Unless specified otherwise, any of these methods may be employed.

2.0 General:

Magnetic particle examination provides for the detection of defects such as cracks and other linear discontinuities in welds, plates, forgings, and castings. Sensitivity is greatest for surface defects and diminishes rapidly with depth below the surface. Magnetic particle examination is applicable only to ferromagnetic materials.

2.1. Description of Method This method of inspection consists of magnetizing the area to be inspected to near saturation and then applying magnetic particles to the surface. The particles will be retained on the surface at cracks and other discontinuities due to leakage in the magnetic field. The patterns will be characterisitc of the type of defect present.

2.2 Magnetization Any suitable means of establishing the necessary magnetic flux may be employed, such as passing a current through the material, by using a magnetic yoke (the section to be inspected being the "keeper") or by wrapping the part or surface with a coil through which magnetizing current is passed.

2.3 Examination Medium The magnetic particles used for detection of defects shall be as follows:

2.3.1 Dry Particles If dry particles are used as the examination medium, they shall be of high permeability and low retentivity and of such size and shape as will produce suitable indications. It is desirable that the color be such as to provide adequate contrast with the background of the surface being inspected.

2.3.2 Wet Particles If wet particles are used, the particles shall be red or black or, alternatively, may be fluorescent when viewed under ultraviolet illumination. The particles shall be suspended in a suitable liquid medium in the concentration recommended by the manufacturer of the particles. Amplified details on the use of wet particles are given in ASTM E-138-58T, Method of Wet Magnetic Particle Inspection.

2.3.3 Orientation of Defects Regardless of the manner of producing the magnetic flux, the greatest sensitivity will be to linear defects lying perpendicular to the lines of flux and the least sensitivity will be to linear defects lying parallel to the lines of flux. Hence, in order to insure most effective detection of defects, it is necessary to inspect each area at least twice with the lines of flux in one case approximately perpendicular to the lines of flux in the other.

2.3.4 Demagnetization Demagnetization following inspection is neither required nor prohibited.

3.0 Surface Preparation:

The surface to be examined, including the surface to which electrical or magnetic connections are to be made, shall be clean and dry and shall be free from oil, grease, sand, loose rust, or scale. Preparation of as-welded, as-rolled, as-cast, or as-forged materials by grinding or machining is required where surface irregularities would mask indications of defects.

4.0 Methods:

4.1 Prod Method

4.1.1 Examination Medium

Magnetic particles in dry from shall be used with the prod method except that for routine production line type of examination of parts such as castings, wet particles may be used.

4.1.2 Magnetizing Technique

Magnetization is accomplished by the use of portable prod type electrical contacts pressed against the surface in the area to be inspected. A remote control switch, which may be built into the prod handles, shall be provided to permit the inspector to turn the current on after the prods have been properly positioned and to turn it off before the prods are removed in order to prevent arcing.

4.1.3 Prod Spacing Prod spacing shall be a maximum of 8 in. Shorter spacing may be used to meet the geometry of the area being examined or to increase sensitivity but prod spacing less than 3 in. usually is not feasible due to banding of the particles around the prods.

Care shall be taken to prevent local overheating or burning of the surface being inspected, particularly on high carbon or alloy materials, since this can cause hard spots or cracks. Lead or steel rather than copper-tipped prods are recommended where the magnetizing voltage is over 25 volts open circuit in order to avoid copper penetration.

4.1.4 Magnetizing Current Direct or rectified magnetizing current normally shall be based on 100 to 125 amperes per inch of prod spacing.

4.1.5 Direction of Magnetization At least two separate inspections shall be carried out on each area. The prods shall be placed so that the magnetizing current during one is approximately perpendicular to the current during the other.

4.1.6 Procedure Prods are positioned on the surface to be examined and the magnetizing current turned on. The particles are then dusted lightly over the surface. Any excess may be removed with a gentle air stream. The air stream should not disturb or remove lightly held particle patterns. In order to recognize the broad, fuzzy, lightly held patterns produced by sub-surface discontinuities, it is essential to observe carefully the formation of indications while the particles are being applied, and also while any excess is being removed. Proper lighting will facilitate observation of these patterns. Indications of defects are noted. The current is then turned off and the prods repositioned for the second inspection of the area.

4.2 Coil Method

4.2.1 Examination Medium - Either dry or wet particles shall be used as the examination medium.

4.2.2 Magnetizing Technique - Magnetization is developed by passing current through a multi-turn coil looped around the part or section of the part that is to be inspected. This produces a magnetic field parallel to the axis of the coil.The magnetic field strength of the coil shall be 3,000 to 10,000 ampere turns.

4.2.3 Magnetizing Current Direct or rectified current shall be used for magnetizing.

4.2.4 Direction of Magnetization At least two separate examinations shall be carried out on each area. The second inspection shall be with current flow approximately at right angles to that used for the first examination in that area. A different means of magnetizing may be used for the second examination.

4.2.5 Procedure After the means of magnetization have been brought into the proper relationship with the surface to be examined, the magnetizing current is turned on. The examination medium is then applied to the area to be examined. Dry particles are applied as described in 4.1.6. If wet particles are used, they are applied typically by spraying, but other appropriate means may be employed. Indications of defects are noted and the second examination of the area is made in accordance with 4.2.4 above.

4.3 Yoke Method

4.3.1 Examination Medium Either dry or wet particles shall be used as the examination medium.

4.3.2 Magnetizing Technique Alternating current electro-magnetic yokes may be used to magnetize provided that the sensitivity to detect surface cracks is at least equivalent to that of the prod method when a direct or rectified magnetizing current of 25 to 30 amperes per inch of prod spacing is used and the lifting power of the yoke is at least 10 lbs. with a pole spacing of 3 to 6 inches.

Permanent magnet yokes may be used to magnetize provided that the sensitivity to detect surface cracks is at least equivalent of the prod method when a direct or rectified magnetizing current of 25 to 30 amperes per inch of prod spacing is used and the lifting power of the yoke is at least 40 lbs. with a pole spacing of 3 to 6 inches.

4.3.3 Direction of Magnetization At least two separate examinations shall be carried out on each area. The second examination shall be with the magnetic flux approximately at right angles to that used in the first examination. A different means of magnetizing may be employed for the second examination of the area.

4.3.4 Procedure After the means of magnetizing have been brought into proper relationship with the surface to be examined, the magnetic particles shall be applied and the examination procedures shall be carried out per reference paragraphs given above.

5.0 Evaluation of Indications:

Defects which occur as mechanical discontinuities at the surface will be indicated by the retention of magnetic particles. All indications are not necessarily defects, however, since certain metallurgical discontinuities and magnetic permeability variations may produce similar indications which are not relevant to the detection of defects.

Any indication which is believed to be non-relevant shall be regarded as a defect until the indication is either eliminated by surface conditioning or it is re-examined by the same or other non-destructive means and proved to be non-relevant. Non-relevant indications which would mask indications of defects are unacceptable.

Relevant indications are those which result from mechanical discontinuities. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length less than three times the width.

6.0 Acceptance Standards:

6.1 Unless other wise specified, the following relevant indications are unacceptable:

(1) Any cracks and linear indications.

(2) Rounded indications with dimensions greater than 3/16"
(3) Four or more rounded indications in a line separated by 1/16" or less edge-to-edge.
(4) Ten or more rounded indications in any six square inches of surface whose minor dimensions is no less than one inch with these dimensions taken in the most unfavorable location relative to the indications being evaluated.

7.0 Repair of Defects:

7.1 Whenever a defect is removed and subsequent welding is not required the affected area shall be blended into the surrounding surface so as to avoid sharp notches, crevices or corners. After a defect is thought to have been removed, the area shall be examined by the magnetic particle method to insure that the defect has been eliminated.

7.2 Welding repairs may not be made by the material producer without approval of the purchaser.

A.2– INSPECTION AND NDT PROGRAM FOR DETERMINING THE CONDITION OF THE INT/3366 REACTOR VESSEL SUBSEQUENT TO THE SITE UPENDING ACCIDENT.

REFERENCE SPECIFICATIONS

1.	M&P Spec. No. 2.4.2.4(b)	Process Specification for Magnetic Particle Examination
2.	M&P Spec. No. 2.4.3.9(b)	Process Specification for Liquid Penetrant Examination
3.	M&P Spec. No. 2.4.4.19 (b)	& Shop Order V-70553, Supp. 2, for Contract 3366 UT Testing Prior to & after Hydro Test of Vessel and Closure Head
4.	Shop Order T-51238, Supp. 31	Bottom Head Instrument Tube Inspections

REFERENCE DRAWINGS

1.	E-234-042	PRESSURE VESSEL FORMING & WELDING
2.	E-234-044	PRESSURE VESSEL FINAL MACHINING
3.	E-234-061	VESSEL SHIPPING RIG ASSEMBLY
4.	SD-3366-20	INSPECTION OF VESSEL-VISUAL
5.	SD-3366-21	INSPECTION OF VESSEL-DIMENSIONAL & FUNCTIONAL
6.	SD-3366-22	INSPECTION OF VESSEL-NON DESTRUCTIVE TESTS

I. Determine if the reactor vessel sustained actual damage by the following inspections. Inspection equipment and inspectors to be furnished by CE.

1. Visual inspection

A. Visual inspection shall be conducted over 100% of the vessel surfaces, I.D. and O.D., and attachments. Special attention shall be given to the following areas:

a. Impact areas on vessel through which loads were transmitted to vessel. These areas shall include vessel surface areas in saddle locations, bottom head jack screw, lifting beam bearing blocks, vessel support pads on nozzles and areas of shipping skid U-bolt contact with nozzles.

b. Vessel mating surface.

c. Top surface of flange including seal ledge ring surface with o-ring grooves.

d. Vessel stud holes containing threaded devices.

e. Instrument tubes in bottom head and monitor tubes in vessel.

f. Main coolant nozzle safe ends including weld preparation for field connections.

g. Outlet nozzle extensions into vessel and areas of contact for nozzle cover retainer beams on I.D. of vessel at both inlet and outlet nozzle locations.

h. Vessel surfaces at U-bolt locations for main shipping skid saddles.

i. Core Lugs.

j. Instrument Tube J-weld locations

1. B. The visual inspection report shall contain the following information:

   a. Map and record the size and locations of any upset metal, indentations, cracks, or other damage to vessel surfaces which are visible and can be measured and/or described.

   b. Report irregularities from the as-shipped condition.

2. Dimensional Inspections

   A. Dimensional inspections shall consist of four (4) diameters measurements a., b., & d. locations below to determine if the vessel sustained deformation with respect to roundness. These diametrical measurements will be taken 90 degrees to each other and will include the horizontal and vertical diameters of vessel with respect to skid runner base. The remaining two diameters shall be measured at 45 degree angles to the vertical and horizontal diameters previously recorded. It will not be possible to use the 90 degree and 45 degree rules for location c. Diameters for this location shall be taken as shown on SD-3366-21. These measurements will be used to determine if deformation occurred but are not intended as a check against previous CE shop inspections.

   a. 182.733" diameter for vertical machined surface immediately above the mating surface.

   b. 172 9/16" diameter immediately above the core support ledge.

   c. 166.000" diameters across diametrically opposed outlet nozzle extensions into vessel (it will not be possible to use the 90 degree rule for this set of measurements.)

   d. 173" diameter located immediately above the core support lugs.

   e. Four (4) diametrical measurements shall be made in the I.D. straight section of nozzles which were captured in the skid by U-bolts. Diameters shall be recorded at 45 degree increments.

2. B. The dimensional inspectional report shall define measurement orientations with respect to axes and results of measurements.

3. Functional Inspections

A. The following functional checks shall be performed:

a. GO-NO-GO thread gage inspections shall be performed on all vessel stud holes which contained threaded devices (lifting beam studs and vessel cover hold down bolts).

b. Two (2) open holes (holes which did not contain threaded devices) near saddle locations shall be checked with GO-NO-GO thread gages. Also, two (2) open holes near horizontal axis relative skid base shall be checked with thread gages.

B. Bottom head instrument tubes shall be rechecked with functional rod and ball inspections to the same requirements as the instrument tubes received in the CE shops.

II. Determine if the vessel sustained actual damage by performing the following Non-Destructive Tests. Test equipment and technicians to be furnished by CE.

1. Magnetic Particle Examination

A. MT impact areas and 12" in all directions beyond boundaries of impact areas on O.D. of vessel. These impact areas are as defined in I. 1.A.a above.

B. In addition to impact areas, MT the vessel O.D. at the extremes of the horizontal axis relative to the skid base, and in the plane of the saddle centerlines. The area to be inspected at these locations will be identical in size to that inspected at the saddle impact locations.

C. MT vessel O.D. in areas to receive UT inspection described in added <u>Section II.3</u>, Items a. & b. below.

II. 2. Liquid Penetrant Examination

A. PT inside clad surfaces in locations on the vessel I.D. corresponding in location and area to those areas receiving MT inspection on O.D. defined above by II.1.

B. In addition to impact areas, PT the vessel I.D. at the extremes of the horizontal axis relative to the skid base, and in the plane of the saddle centerlines. The areas to be inspected at these locations will be identical in size to that inspected at the saddle impact locations.

C. PT vessel I.D. in areas to receive UT inspection described in added <u>Section II.3</u>.

3. Ultrasonic Examination

A. UT flange to upper shell girth seam (7-042) plus base metal one plate thickness each side of weld centerline geometry permitting. The length of the weld to receive this inspection will correspond to the circumferential length inspected in the saddle impact areas.

B. UT long seam welds (1-042 A & B) plus one plate thickness each side of weld centerlines for full length of upper shell except where nozzles interrupt.

C. UT saddle impact areas.

III. Upon completion of the above scope of inspections and evaluation of results, CE will advise WNES if further tests and inspections will be required to establish the integrity of this vessel to CE's satisfaction.

IV. Depending upon the results of the above scope of inspections and tests, CE will determine what analytical conclusions can be made.

NOTES:

1. CE Materials and Process Specifications used for original shop inspection will be used for all Program Inspections. The recording levels and acceptance criteria shall be identical to that of the original CE shop inspections.

2. WNES shall advise CE when the vessel will be in a condition to conduct the above tests. The vessel must be positioned such that inspectors and equipment have access to impact areas and can be inspected. The lift beam, vessel cover, nozzle covers and vinyl protective covers must be removed. WNES shall have the responsibility of protection of the vessel for the duration of the tests.

3. Inspection, Engineering, and miscellaneous expenses to CE associated with this incident will be for WNES' account. The Field Service Article shall apply for work performed in the field.

A.3 — PROCESS SPECIFICATION FOR LIQUID PENETRANT EXAMINATION — ASME Section III

COMBUSTION ENGINEERING, INC.
NUCLEAR COMPONENTS DEPARTMENT

M&P SPEC. No.: 2.4.3.9(b)
DATE: MAY 3, 1966
SHEET: 1 of 5

PROCESS SPECIFICATION FOR LIQUID PENETRANT EXAMINATION - ASME SECTION III

1.0 Scope:

1.1 This Process Specification provides for the method and standard of acceptance for liquid penetrant testing of nuclear components.

1.2 The penetrant test method is used for detecting the presence of discontinuities in ferrous and nonferrous materials. Discontinuities not open to the surface will not appear since penetration into an open defect is necessary before this method will work. For this reason its use is generally limited to the nonferrous metals and nonmagnetic steels.

Type I - Dye penetrant (water washable)
Type II - Dye penetrant (nonwater washable)
Type III - Fluorescent penetrant (integral emulsification)
Type IV - Fluorescent penetrant (post emulsification

2.0 Surface Preparation:

2.1 General - Surface of welds, castings, or wrought metals may be inspected without surface preparation or conditioning except as required to remove scale, slag, and adhering or imbedded sand. Blasting shall be accomplished by using angular or subangular cutting type sand, silicon carbide, or alumina grit. When blast peening, using steel shot, etc., is necessary before the penetrant inspection test, the blast peening shall be followed by blasting with angular or subangular cutting type sand, silicon carbide, or alumina grit, or by chemical cleaning. "As welded" surfaces, following the removal of slag, shall be considered suitable for liquid penetrant inspection without any grinding, provided the weld contour blends into the base metal without undercutting, and the contour and surface finish of the weld is in accordance with applicable specifications.

3.0 Test Procedures:

3.1 Pretest Cleanliness - All materials being tested shall be cleaned by hot running water, by dipping in a solvent or acetone or by swabbing with a clean cloth saturated with a solvent or acetone.

3.2 The temperature of the penetrant and the part to be inspected shall be maintained between 50°F and 125°F. When inspection is necessary under conditions where the temperature of the penetrant and the inspection surface is outside the 50°F to 125°F range, the temperature shall be adjusted to bring them within the range. Due to the flammable nature of liquid penetrant inspection materials, the use of an open flame for heat purposes is prohibited.

3.3 The surface to be tested shall be thoroughly coated with penetrant by spraying, brushing, or immersion. The surface shall be kept wetted for the minimum time specified for the method employed:

Penetrant	Penetration Time all Applications
Type I	30 minutes
Type II	10 minutes
Type III	30 minutes
Type IV	10 minutes

3.4 The type IV emulsifier shall be applied either by dipping or spraying the part. It should not be applied by means of a brush since stroking with a brush may remove the penetrant from shallow or scratch like discontinuities. After a suitable penetration time and emulsification period the surface film of the penetrant and emulsifier shall be removed from the part by employing a hot water spray not exceeding 50 psi or 110°F. Washing shall be checked under a black light to insure complete cleaning of all surfaces. Alternatively, the penetrant may be removed by use of the cleaner recommended by the manufacturer of the penetrant.

3.5 The penetrant of Types I and III shall be removed from all surfaces by swabbing with a clean cloth saturated with clear water or by spraying with water at moderate pressure. Alternatively, the penetrant may be removed by wiping the excess penetrant from the test surface with a clean dry cloth followed by wiping the partially cleaned surface with an alcohol dampened clean cloth until all traces of the penetrant have been removed.

3.6 The Type II penetrant shall be removed from all test surfaces by wiping with clean cloth dampened with the cleaner recommended by the manufacturer. Excessive application of the cleaner shall be avoided to prevent the possibility of removing the penetrant from discontinuities, causing a decrease in the sensitivity of the test.

3.7 The drying of test surfaces shall be accomplished by using circulating air, blotting with paper towels or clean cloth or normal evaporation. It is important that in the drying operation , no contamination of material such as oil from air nozzles or lint from rags be introduced into the surface which may cause misinterpretation during the inspection operation.

3.8 Dry developing powders shall be uniformly applied to surfaces resulting in a dust like appearance. Dry developers require a dry surface before application, or it will mat heavily on the wet surfaces. A short time shall be allowed for development of indications after the developing powder is applied. This time shall be about half as long as the time allowed for penetration.

3.9 Wet type developers shall be uniformly applied to surfaces by dipping, spraying, or brushing. When using liquid type developers, it is necessary that they continually agitate in order to prevent settling of solid particles dispersed in the liquid. Pools of wet developer in cavities on the inspection surface shall be avoided since these pools will dry to an excessively heavy coating in such areas resulting in the masking of indications. Inspection shall be made a

4.0 Evaluation of Indications:

4.1 Defects which occur as mechanical discontinuities at the surface will be indicated by bleeding out of the penetrant; however, localized surface imperfections such as may occur from machining marks or surface conditions may produce similar indications which are not relevant to the detection of defects.

4.2 Any indication which is believed to be non-relevant shall be regarded as a defect until the indication is either eliminate by surface conditioning or it is evaluated by non-destructive means and proved to be non-relevant. Non-relevant indication and broad areas of pigmentation which would mask indications of defects are unacceptable.

4.3 Relevant indications are those which result from mechanical discontinuities. Linear indications are those indications in which the length is more than three times the width. Rounded indications are indications which are circular or elliptical with the length less than three times the width.

5.0 Acceptance Standards:

5.1 The following types of relevant indications are not acceptab

(1) Cracks or linear indications

(2) Rounded indications with dimensions greater than 3/16"

(3) Four or more rounded indications in a line separated by 1/16" or less edge-to-edge.

(4) Ten or more rounded indications in any six square inche of surface whose minor dimension is no less than one inch, with these dimensions taken in the least favorabl location relative to the indications being evaluated.

COMBUSTION ENGINEERING, INC.
NUCLEAR COMPONENTS DEPARTMENT

M&P Spec. No.: 2.4.3.9(b)
Date: May 3, 1966
Sheet: 5 of 5

5.2 Whenever a defect is removed and subsequent repair by welding is not required, the affected area shall be blended into the surrounding surface so as to avoid sharp notches, crevices or corners.

5.3 After a defect is thought to have been removed, and prior to making repairs, the area shall be examined by suitable methods to insure that the defect has been eliminated.

5.4 After repairs have been made, the repaired area shall be re-examined by the liquid penetrant method and by all other methods of examination that were originally required for the affected area.

A.4 —SPECIFICATION FOR ULTRASONIC TESTING OF PLATE MATERIAL

COMBUSTION ENGINEERING, INC.
NUCLEAR COMPONENTS DEPARTMENT

M&P SPEC. NO.: 2.4.4.19(b)
Date: February 17, 1966
Sheet: 1 of 3

SPECIFICATION FOR ULTRASONIC TESTING OF PLATE MATERIAL

1.0 Scope:

1.1 This specification provides for the method and technique for ultrasonic testing of flat or shaped plate exceeding 3/8" thickness in accordance with the requirements of ASME Code Case 1338-2.

1.2 Ultrasonic testing to the requirements of this specification may be a provision of the purchase order, or it may be required by reference to this specification in a Material Purchase Specification. This specification also shall govern C-E shop inspection of plate when required by shop order.

2.0 Equipment and Surface Conditions for Longitudinal Wave Testing:

2.1 Pulse-reflection type equipment (Sperry UR Reflectoscope or equivalent) shall be used with the single crystal contact method of ultrasonic testing of plates over 3/8" in the thickness. Plates 3/8" and less in thickness will be tested by methods mutually agreed to by the manufacturer and purchaser.

2.2 Ultrasonic testing shall be performed using longitudinal wave 1-1/8" diameter 2¼ Mc crystals. A frequency of 1 Mc may be used for plate thickness over 8 inches. Deviations from this procedure may be requested of the purchaser. Crystals of other sizes and frequencies may be used for exploration or study of flaw indications.

2.3 The surface of plate to be tested shall be clean and free of dirt, excessive roughness or loose scale.

2.4 A suitable liquid sonic couplant shall be used in sufficient quantity so that continuous sonic contact can be maintained.

3.0 Degrees of Testing:

3.1 Longitudinal wave testing shall be performed on 100% of one surface of the plate. Scanning for defects shall be performed along parallel lines drawn on the plate, or indicated at the plate edges, at a spacing not greater than the crystal width. Complete loss of back reflection appearing on the screen shall be investigated by searching over the area until the boundary of the area producing loss of back reflection is established.

4.0 Calibration:

4.1 Calibration sensitivity shall be established for longitudinal wave testing by adjustment of the instrument so that the back reflection is approximately 50 to 75% of screen height.

5.0 Test Results:

5.1 Acceptance - Any defect which shows a total loss of back reflection that cannot be contained within a circle whose diameter is the greater of 3 inches or 1/2 of the plate thickness shall be unacceptable.

5.2 Two or more defects smaller than described in 5.1, which cause a complete loss of back reflection shall be unacceptable unless separated by a minimum distance equal to the greatest dimension of the larger defect unless the defects are contained within the area described in 5.1.

5.3 A report shall be made to the purchaser, prior to shipment of plate, where discontinuities are disclosed which reduce the back reflection by 50% or more; or where discontinuities are disclosed which produce traveling indications accompanied by a reduced back reflection.

6.0 Equipment and Surface Conditions for Shear Wave Testing:

6.1 Ultrasonic testing shall be performed with a 45° quartz shear wave transducer at a frequency of 1 Mc.

COMBUSTION ENGINEERING, INC.
NUCLEAR COMPONENTS DEPARTMENT

M&P Spec. No.: 2.4.4.19(b)
Date: February 17, 1966
Sheet: 3 of 3

6.2 The surfaces of plate to be tested shall be clean and free of dirt, excessive roughness or loose scale.

6.3 A suitable liquid sonic couplant shall be used in sufficient quantity to provide continuous sonic contact.

7.0 Degree of Testing:

7.1 Inspection shall be 100% volumetric and from two perpendicular directions.

8.0 Calibration:

8.1 The calibration standard shall be a 3% notch (3% of plate thickness, one inch in length).

9.0 Test Results:

9.1 Indications having an amplitude exceeding the calibration standard shall be charted showing approximate location and magnitude.

10.0 Records:

10.1 A plan diagram of each plate tested which shows indications of the type referenced in Paragraph 5.0 and 9.0 shall be prepared. This plan diagram will consist of marking such defects or areas in approximate actual location with the required dimensions and also the location of the mill heat number stampings.

A.5 — UT TESTING OF BASE METAL

COMBUSTION ENGINEERING, INC
CHATTANOOGA DIVISION
SHOP ORDER

OF N.Y. ORDER	SUPP. DATE	SHEET OF	SHOP ORDER NO. V-70553	SUPP. NO. 2	DATE 7/19/68
JECT UT Testing of Base Metal		CONT. NO. 3366		SECTION	ORDER NO.
STOMER ORDER NO.	REQ'N. NO.	SUPP. NO.	SHIP TO AND MARK		

Westinghouse Electric Corporation

UT TESTING PRIOR TO & AFTER HYDRO TEST OF VESSEL & CLOSURE HEAD

The reactor vessel and closure head shall be ultrasonically tested after successful completion of the hydrostatic test in accordance with the following:

1. AREAS TO BE TESTED
   1. Exterior machined surface of the closure head and [illegible] conical portion of the flange forgings
   2. Vessel flange
   3. Main Coolant Nozzles
   4. Middle shell course
   5. Lower shell course above core support lugs
   6. Nozzle to upper shell welds
   7. Middle shell to lower shell weld
   8. Upper shell to middle shell weld
   9. Flange to upper shell Weld
2. SURFACE PREPARATION FOR TESTING
   The cladding surface in the areas to be tested shall be suff[illegible] smooth & uniform to insure the desired sensitivity of the testing. When grinding is performed to improve the cladding surf[illegible] the [illegible] shall be reduc[illegible]

T. Davis

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ON ENGINEERING, INC.

ROAD WINDSOR, CONNECTICUT

CONTINUATION SHEET

NO.	JOB NO.	ACCT. NO.		ORDER NO.	SUPP NO.	SHEET	
3366				V-70553	2	2	2

QUANTITY DESCRIPTION

that the valley between beads is still discernible thus maintaining the clad thickness.

3. SPECIFICATION AND TECHNIQUE

a. Ultrasonic testing shall be performed in accordance with M&P Specification 2.4.4.19(b); however, acceptance criteria of Para. 5.0 shall not apply.

b. The shear wave and longitudinal wave testing will be performed utilizing the wheel transducer where possible. The nozzles and other areas where required by reasons of geometry will be tested by the contact or bubble technique. Shear wave testing shall be conducted with the beam directed toward the top of the vessel for all girth seams and additionally in a clockwise direction.

4. TEST RESULTS AND RECORDS

Accurate maps of recordable indications will be provided showing the radial location of defects in 1/2° increments, the axial location will be measured from the mating surface of the flanges within ± 1/16". Where surface condition or geometry preclude a back reflection, recordings will be based on any indication exceeding 40% of the initial calibration amplitude.

In addition to the above standards, the following additional recording information should be considered where applicable:

1) When back reflection is reduced to 40% or less of the original calibrated back reflection due to the presence of discontinuity indications.

2) Amplitude of the discontinuity indications noted in (1) above as a % of the established back reflection amplitude shall be recorded in 10% increments.

3) Depth of discontinuity indication recorded under [illegible] above

In areas where non-parallel surfaces exist, the report will be based on discontinuity indication amplitude and depth rather than on loss of reflection. Reporting levels will be defined by the Inspection Rep. their report & discontinuity indications shall be based on reference using 1/2 inch diameter flat bottom holes.

This shop order previously released the UT prior to final stress relief for the subject vessel in the same areas, and so the [illegible] for the final UT. Monetary and schedule consideration was given to the preliminary UT in our quotation WAPD.

B.1 — PROCEDURE EMPLOYED IN SECOND MAGNETIC PARTICLE TEST

The following procedure shall be followed to establish magnetic particle testing parameters for Indian Point Number 3 reactor vessel examination relative to up-ending accident damage evaluation.

1. Place test equipment calibration plate in position so that cracked surface is in the overhead position.
2. With lighting, magnetic particle test yoke, the iron particle powder, and the device for applying the powder to be used in actual testing, the technique for testing shall be demonstrated.
3. Upon establishment of a technique which clearly defines the cracks in the calibration test plate under fixed lighting conditions, the following test parameters shall be recorded and shall be applied in all subsequent magnetic particle testing.
    - (a) Number of light sources, their power (wattage), and their arrangement with respect to test equipment and test area.
    - (b) The length of time magnetizing current is applied to the test device for each direction employed.
    - (c) Length of time powder is applied to the magnetized area (specify) with respect to application while current is being applied as well as after current is stopped.
    - (d) Pressure (psi) of air supply to magnetic powder applying device.
4. Evaluation of test results shall be made for each test direction individually.

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*Attachment to an ORNL Intra-Laboratory memorandum from R. O. arden and R. M. Fuller to R. W. McClung, dated May 7, 1971. (See Appendix F of Final Report).

APPENDIX B – SECOND POST-INCIDENT INSPECTION PROCEDURES

B.1 – Procedure Employed in Second Magnetic Particle Test........B2

B.2 – Specification for Ultrasonic Testing of Plate Material.....B3

B.2 – SPECIFICATION FOR ULTRASONIC TESTING OF PLATE MATERIAL

COMBUSTION ENGINEERING, INC.
NUCLEAR COMPONENTS DEPARTMENT

SECOND ULTRASONIC INSPECTION FOR
INT/3366 REACTOR VESSEL SITE ACCIDENT
APRIL 27, 1971
WNES, ORNL, C-E MEETING AGREEMENT
SHEET 1 of 3

SPECIFICATION FOR ULTRASONIC TESTING OF PLATE MATERIAL

1.0 Scope:

1.1 This specification provides for the method and technique for ultrasonic testing of flat or shaped plate exceeding 3/8" thickness in accordance with the requirements of ASME Code Case 1338-2.

1.2 Ultrasonic testing to the requirements of this specification may be a provision of the purchase order, or it may be required by reference to this specification in a Material Purchase Specification. This specification also shall govern C-E shop inspection of plate when required by shop order.

2.0 Equipment and Surface Conditions for Longitudinal Wave Testing:

2.1 Pulse-reflection type equipment (Sperry UR Reflectoscope or equivalent) shall be used with the single crystal contact method of ultrasonic testing of plates over 3/8" in the thickness. Plates 3/8" and less in thickness will be tested by methods mutually agreed to by the manufacturer and purchaser.

2.2 Ultrasonic testing shall be performed using longitudinal wave 1-1/8" diameter 2-1/4 Mc crystals. A frequency of 1 Mc may be used for plate thickness over 8 inches. Deviations from this procedure may be requested of the purchaser. Crystals of other sizes and frequencies may be used for exploration or study of flaw indications.

2.3 The surface of plate to be tested shall be clean and free of dirt, excessive roughness or loose scale.

2.4 A suitable liquid sonic couplant shall be used in sufficient quantity so that continuous sonic contact can be maintained.

COMBUSTION ENGINEERING, INC.
NUCLEAR COMPONENTS DEPARTMENT

SECOND ULTRASONIC INSPECTION FOR
INT/3366 REACTOR VESSEL SITE ACCIDENT
APRIL 27, 1971
WNES, ORNL, C-E MEETING AGREEMENT
SHEET 2 of 3

3.0 Degrees of Testing:

3.1 Longitudinal wave testing shall be performed on 100% of one surface of the plate. Scanning for defects shall be performed along parallel lines drawn on the plate, or indicated at the plate edges, at a spacing not greater than the crystal width. Complete loss of back reflection appearing on the screen shall be investigated by searching over the area until the boundary of the area producing loss of back reflection is established.

4.0 Calibration:

4.1 Calibration sensitivity shall be established for longitudinal wave testing by adjustment of the instrument so that the back reflection is approximately 50 to 75% of screen height.

5.0 Test Results:

5.1 Acceptance - Any defect which shows a total loss of back reflection that cannot be contained within a circle whose diameter is the greater of 3 inches or 1/2 of the plate thickness shall be unacceptable.

5.2 Two or more defects smaller than described in 5.1, which cause a complete loss of back reflection shall be unacceptable unless separated by a minimum distance equal to the greatest dimension of the larger defect unless the defects are contained within the area described in 5.1.

5.3 A report shall be made to the purchaser, prior to shipment of plate, where discontinuities are disclosed which reduce the back reflection by 50% or more; or where discontinuities are disclosed which produce traveling indications accompanied by a reduced back reflection. (In this paragraph, the gain of the instrument shall be increased to provide a 90% back reflection in an indication-free area).

5.3 Continued

a) Amplitude of the discontinuity indications noted in 5.3 above as a % of the established back reflection amplitude shall be recorded in 10% increments.

b) Depth of discontinuity indication recorded under (a) above.

6.0 Equipment and Surface Conditions for Shear Wave Testing:

6.1 Ultrasonic testing shall be performed with a 45° quartz shear wave transducer at a frequency of 1 Mc. or 2 1/4 Mc

6.2 The surfaces of plate to be tested shall be clean and free of dirt, excessive roughness or loose scale.

6.3 A suitable liquid sonic couplant shall be used in sufficient quantity to provide continuous sonic contact.

6.4 Degree of Testing:

6.4.1 Inspection shall be 100% volumetric and from two perpendicular directions.

6.5 Calibration:

6.5.1 The calibration standard shall be a 3% notch (3% of plate thickness, one inch in length). (For Each Perpendicular Direction)

6.6 Test Results:

6.6.1 Indications having an amplitude exceeding the calibration standard shall be charted showing approximate location And magnitude.

7.0 Records:

7.1 Accurate maps of recordable indications will be provided showing the radial location of defects in 1/2° increments, the axial location will be measured from the mating surface of the flange within ± 1/16", and surface conditions which preclud a back reflection.

Appendix C

ASSESSMENT OF THE EFFECTS OF A LET-DOWN INCIDENT ON THE INDIAN POINT UNIT 3 REACTOR PRESSURE VESSEL, BASED ON STRESS ANALYSIS AND FRACTURE MECHANICS

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Introduction

On January 12, 1971, WEDCO personnel were in the process of lifting the Indian Point Unit 3 Reactor Vessel inside the Containment Building in preparation for removing the vessel shipping skid. During this operation, failure occurred in the lifting equipment causing the reactor vessel to roll from a vertical or near vertical position to a horizontal position. Since the lifting process was interrupted by the let-down incident, the vessel shipping skid was still firmly attached to the vessel. The eccentricity of the shipping skid caused the vessel to roll back down onto the skid rails, and the skid prevented the vessel from receiving any impact loads directly from the temporary supporting floor. All of the impact forces received by the vessel were therefore transmitted to it through the shipping skid. The vessel came to rest in a position partly overhanging the edge of the temporary supporting floor. The temporary supporting floor was constructed of 24-in.-deep wide flange steel beams laid side by side over the reactor well between two concrete shield walls and was then covered with a steel deck plate. Additional steel plate and channels had been placed on the deck directly beneath the shipping skid rails. Web buckling occurred at the ends of six of the floor beams located nearest the point where the left rail of the shipping skid extended off the edge of the floor. Except for one broken and some other loose bolts in the shipping skid no other structural damage was visible in the floor, skid, or vessel.

Stress Analysis and Critical Flaw Size Calculations

The objective of a stress analysis, in this case, is to provide data with which to make a calculation of the smallest flaw that could have become critical (i.e., that could have caused an extension of the flaw) during the incident. If this flaw is sufficiently greater in size than some lower limit of detectability that can be agreed upon, and no evidence of flaws this large is found, then the vessel can be presumed to have been unaffected by the incident. Since the maximum force acting on the vessel and its distribution must be estimated, the overall series of calculations must be made with conservatism. One approach is to rely on the results of the visual, dimensional, and functional inspections performed after the incident, which revealed no evidence of gross distortion, and to assume that the maximum stresses in the vessel could have reached, but not exceeded, the yield stress. This approach avoids the problem of estimating the load on the vessel and its distribution and, coupled with the assumption that regions of local embrittlement are either of limited size or do not exist at all, allows the calculation of critical flaw sizes based on the static (or at least not the minimum dynamic) fracture toughness. The high fracture toughness existing near the surfaces due to quenching and tempering is considered in this approach. Here the stress analysis conditions are meant to be conservative, and the metallurgical conditions are meant to be realistic.

Another approach is to make the stress analysis conditions more realistic, by estimating the load, and to evaluate the fracture toughness more conservatively by using the minimum dynamic (i.e., the crack arrest) fracture toughness. Both approaches have been taken, and they are described below.

Conservative Stress Analysis, Realistic Metallurgical Conditions

(D. A. Canonico)

Current thick-walled nuclear pressure vessels are fabricated from low alloy high strength steel plate which has been quenched in water and tempered to achieve its optimum mechanical properties. Such heat treatments in thick (five inches and above) plate result in a through-the-thickness variation in cooling rate. These cooling rate differences result in a variation in mechanical properties from the surface to a depth of about 1 1/2 in. in ASTM A 533 grade B class 1 steel. (This is the steel employed in the fabrication of most light-water nuclear pressure vessels.) Studies[1] in the Heavy-Section Steel Technology (HSST) program at Oak Ridge National Laboratory have reported that the yield strength for 12-in.-thick steel plate varies from about 85,000 psi at the surface to about 69,000 psi at the 1/4-thickness to 3/4-thickness locations. (The ASTM specification for this steel requires 50,000 psi minimum yield strength for class 1 steel and 70,000 psi minimum yield strength for class 2 steel.) Further, the toughness, as measured by the 30 ft-lb Charpy V notch impact energy criterion varies from about -150°F at the surface to about +10°F at the 1/4-thickness to 3/4-thickness locations. The variation in properties is true for all quenched and tempered pressure vessels and should be considered in the evaluation of an upending accident such as was suffered by the Indian Point 3 reactor vessel. The above reasoning regarding the variation in properties due to metallurgical variations in the surface material has been considered in the application of fracture mechanics to the determination of the critical flaw size to cause failure.

Work done by Westinghouse Electric Corporation[2] in connection with the HSST Program has provided us with the fracture toughness, K_{Ic}, as a function of temperature for a steel whose specification is identical to that employed in the Indian Point 3 pressure vessel. Further, their work and others have shown that $\frac{\sigma_y}{K_{Ic}} \sim 1$ at the nil ductility transition temperature (NDTT). Based on this assumption we have determined K_{Ic} versus temperature curves for surface and 1/8-thickness locations for these steels. These curves are presented in Fig. 1. This figure provides static fracture toughness values which can be assumed to be applicable to the surface, 1/6-thickness and 1/3-thickness locations for the Indian Point 3 reactor vessel. The dynamic fracture toughness for these same locations is also presented in Fig. 1. These dynamic values are also based on work reported by Westinghouse Electric Corporation. The K_{Id} curve is displaced about 90°F higher in temperature than the K_{Ic}. This 90° value is assumed to be true for the surface and 1/6-thickness locations.

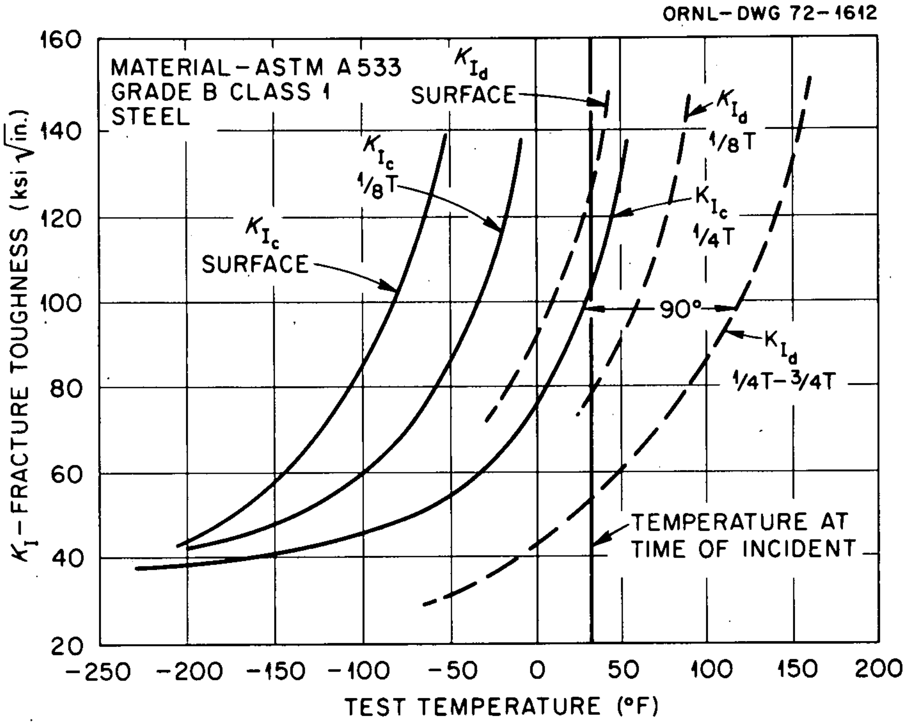


Figure 1 Fracture Toughness vs Temperature.

The upending accident resulted in the vessel being stressed at a rate somewhere between the static and dynamic conditions considered in Fig. 1. A reasonable value can probably be obtained by assuming a fracture toughness value somewhere between these two extremes. An average, such as that obtained with the following equation, will probably provide reasonably accurate values for the fracture toughness of the vessel at the time of the accident.

$$K_{I(Ave)} = \frac{K_{Ic} + K_{Id}}{2} \qquad (1)$$

If the K_{Ic} and K_{Id} values are taken at +32°F (the temperature at the time of the accident) then the fracture toughness is as follows:

Location	K_{Ic} ksi $\sqrt{in.}$	K_{Id} ksi $\sqrt{in.}$	K_{I} (Ave) ksi $\sqrt{in.}$
Surface	>200	125	200
1/6T	>200	80	140
1/3T	103	55	79

The above K_I values permit the calculation of a critical flaw size (if a stress is assumed) or a critical stress (if a flaw size is assumed). A conservative estimate, made by the ORNL inspection team, of the size of the largest flaw that could have been missed by the reinspection was conservatively set at 2 in. Moreover, the dimensional check determined that the vessel did not undergo plastic deformation due to the let-down accident. Hence a maximum outer fiber stress of about 85,000 psi is also established. This information provides two extremely important points which permit an assessment of damage to the Indian Point 3 reactor vessel based on fracture mechanics.

The fracture toughness of a material can be determined by the following equation:

$$K_{Ic} = C\sigma_f\sqrt{\pi a} \quad , \qquad (2)$$

where C is the shape factor for the flaw, σ_f is the fracture stress, and a is the flaw size. For the flaws considered in this evaluation a shape factor of 0.9 is appropriate. Equation (2) provides the basis for assessing the damage that could have been imposed in the reactor vessel due to the upending accident. Calculations have been made based on an average fracture toughness value for the material at the temperature of the accident. Stress values of 85,000 psi and 50,000 psi (the minimum yield strength for ASTM A 533 grade B class 1 steel) have been employed in these calculations. Critical flaw sizes to produce failure have been determined. These results are listed in Table I. It is evident that the critical flaw size is greater than 2 in. regardless of the location considered. This is true even for the extremely high 85,000 psi outer fiber stress value.

Table 1. Critical Flaw Sizes Based on Average Fracture Toughness Value for ASTM A533 Grade B Class 1 Steel

Stress (ksi)	Location, Distance Below Surface-in.	Fracture Toughness (ksi in.)	Critical Flaw Size (in.)
85[a]	Surface	200	2.16
75[a]	1/2	180	2.25
60[a]	1	160	2.37
55[a]	1 1/2	140	2.52
28[a]	3	79	3.12
50[b]	Surface	200	6.25
33[b]	1 1/2	140	7.02
16[b]	3	79	9.5

[a] Assumes stress of 85 ksi to outer fibers.

[b] Assumes stress of 50 ksi to outer fibers.

Perhaps, however, one could be accused of unconservatism for using the stress value at the crack tip because it is indeed a lower value than the total integrated stress that would be operable over the entire flaw. To avoid this criticism we have made a calculation based on an average stress and an average fracture toughness over the entire area considered.

$$\text{Average stress} = \frac{\text{outer fiber stress} + \text{stress at depth of interest}}{2} \qquad (3)$$

Average fracture toughness =

$$\frac{K_{I_{Ave}} \text{ at surface} + K_{I_{Ave}} \text{ at depth of interest}}{2} \qquad (4)$$

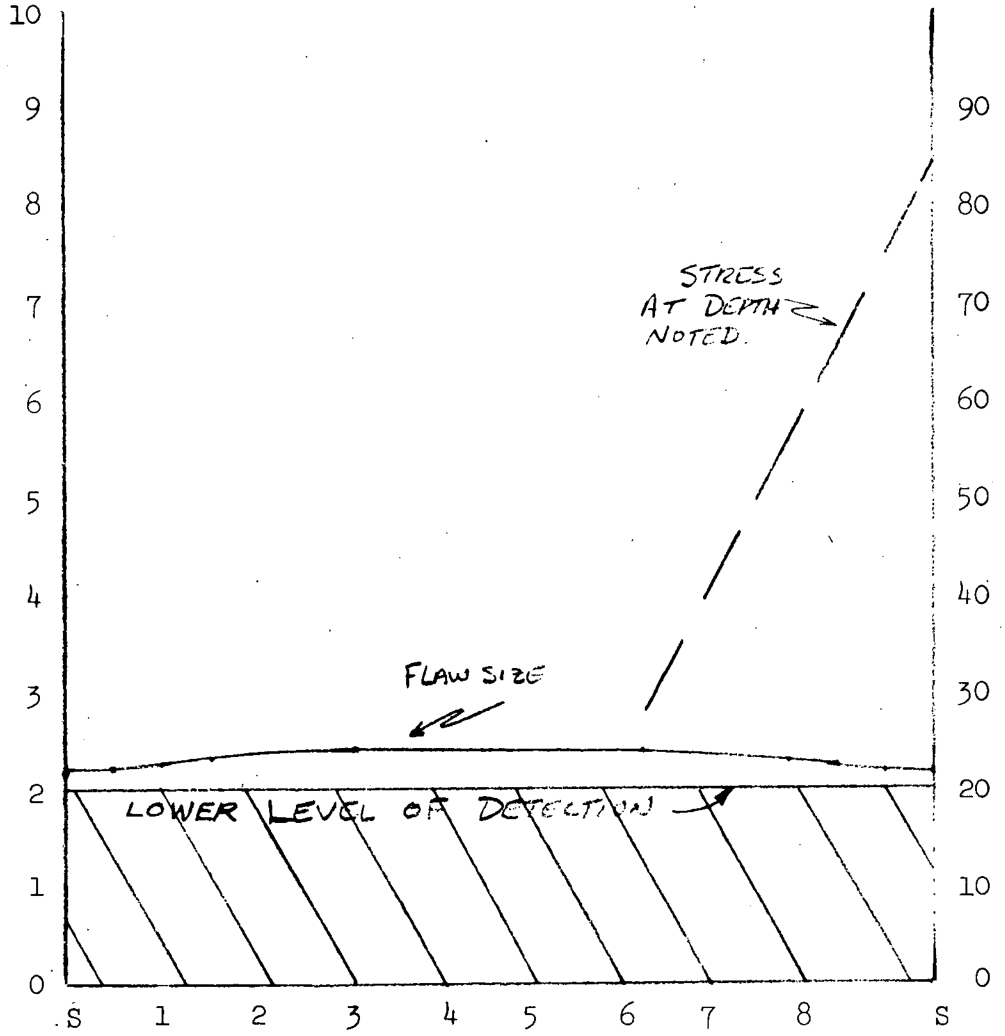
Calculations based on these assumptions resulted in the critical flaw sizes reported in Table II. The flaw sizes are quite similar; no flaw of the maximum undetected size, 2 in., would case failure under the stress levels considered. Figure 2 shows the distribution of the critical flaw size to cause failure at the various depth locations in the Indian Point 3 reactor pressure vessel.

As further assurance that this interpretation of the effects of the upending accident is reasonable, we calculated the stress necessary to cause failure if the maximum size undetected flaw were present. These results are presented in Table III. It is evident that, based on a flaw size of 2 in., the stress levels required to cause failure are quite high.

The above assessment, based on a combined metallurgical and fracture mechanics approach to possible damage to the Indian Point 3 reactor pressure vessel due to the upending accident, is reassuring. This analysis indicates that the maximum possible flaw size present in the regions of highest impact due to the upending accident could not have caused damage to the vessel. Therefore, based on this analysis, my conclusion would be that the vessel was not damaged due to the upending accident at the Indian Point 3 site on January 12, 1971.

Figure 2

Flaw Size to Cause Failure at Various Depth Locations
in the Indian Point III Reactor Pressure Vessel
Upending Accident



Location Through the Thickness — Inches

Table II. Critical Flaw Sizes Based on an Average Stress and Average Fracture Toughness Over the Area Under Consideration

Stress[a] (ksi)	Location, Distance Below Surface-in.	Fracture Toughness[b] (ksi in.)	Critical Flaw Size (in.)
85	Surface	200	2.16
80	1/2	190	2.20
75	1	180	2.25
70	1 1/2	170	2.30
56.5	3	140	2.40

[a] Stress on Outer Fibers + Stress at Depth of Interest/2.

[b] Average Fracture Toughness at Surface + Average F.T. at Depth of Interest/2.

Table III. Stress Required to Cause Failure In ASTM A533 Grade B Class 1 Steel When Flaw Size of 2 in. is Present

Assumed Fracture Toughness (ksi in.)	Depth, Location Represented by Fracture Toughness Value	Fracture Stress (ksi)
200	Surface	88.0
140	1 1/2 in.	61.5
125	2 in.	55.0
100	2 i/2 in.	44.0
80	3 in.	35.2
55[a]		24.2

[a] Dynamic fracture toughness values for 1/3 T to 2/3 T locations through the plate.

Realistic Stress Analysis, Conservative Metallurgical Conditions (J. G. Merkle)

a) Load estimate. In this approach the intent is to determine from external evidence the magnitude of the vessel stresses during its impact. An estimate of the peak reaction force acting between the temporary supporting floor and the reactor vessel is required before such a stress analysis can be performed. Such an estimate might be obtained from a dynamic analysis of the vessel, skid, and floor; but such an analysis would be complicated and would be subject to inaccuracies because of lack of knowledge of the time variation of the crane force during the let-down incident. However, advantage can be taken of the fact that the vessel came to rest near one side of the temporary supporting floor and that buckling occurred in the webs of six of the floor beams located directly beneath the vessel. Since buckling occurs at nearly constant stress, and compression members of mild steel require very closely spaced lateral bracing to raise the buckling stress above the yield stress, it is conservative to estimate the web buckling stress as the yield stress. Multiplying the total thickness of the buckled webs (6 x 1/2") by the bearing distance on the concrete shield wall (~2.5') by an assumed yield stress of 40 ksi gives an estimated force of 1800 tons. The total weight of the lift was 441 tons (see Dadson's memo of 1/13/71). Therefore, the estimated reaction force is 4.08 times the weight of the lift. The average vertical deflection of the buckled beam webs is about 1/2 in. Equating the work done in buckling to the potential energy of the lift gives an effective free drop height of only 1 1/2 in.

It has been assumed for the following stress analysis calculations that the reaction force applied to the vessel was 1800 tons. This amounts to ignoring the additional load transmitted to the vessel from the other end of the floor beams; but this basis also implies a probable overestimation of the buckling stress in the floor beam webs. Calculations indicate that considering the second beam reaction could raise the force applied to the vessel by about 20%; but considering the rotation imposed upon the top flanges of the beams that buckled, by the deflection of the deck plate, could lower the buckling stress by as much as 60%. Thus, the original load estimate of 1800 tons is still considered conservative.

b) Load distribution. The load distribution on the vessel is not known exactly. It is probable that most of the peak load was transmitted to the vessel through the forward pair of skid supports, because of the vessel's rotational momentum, and that the forces acting through these two skid supports may not have remained exactly equal, because of leaning of the skid and vessel. However, the bending stiffness of the top flange and the nozzle course should be greater than that of main cylindrical region below the nozzle course, because of greater wall thickness. Therefore, the analytical model chosen is a plain cylinder having the inside diameter (173.4") and the thickness (8.84") of the main cylindrical region, and an axial length of 142 in., which is the distance between the middle and the rear skid supports. The support reactions are assumed to be equal, and are applied as point loads at angles of 35.5° from the lower part of the vertical centerline of the vessel. The skid supports actually each have a bearing area of 768 square in., so that the bearing stresses on the vessel wall are 2340 psi, acting through sheets of compressible plywood. Considering the reactions on the vessel as point loads should help to compensate for the fact that the skid supports are not continuous in the axial direction. The inertia forces acting on the vessel are considered as a uniformly distributed vertical load of 44.3 psi. The solution to the model chosen is found in Roark, "Formulas for Stress and Strain," Third Edition, McGraw Hill, 1954, case no. 19, p. 160.

c) Stress analysis. The stresses calculated are due to bending only. Some through thickness stresses do exist, but they are small compared to the bending stresses. A polar plot of the maximum bending stresses is shown in Fig. 3, with the direction of plotting from the zero line indicating the surface of the vessel at which the bending stress is tensile. The maximum calculated bending stress is 11,600 psi, and it occurs on the outside surface of the vessel, at an angle of 84.4° from the lower part of the vertical centerline. The maximum bending stress directly beneath the skid supports is almost the same in magnitude, 11,000 psi, and it is tensile on the inside surface.

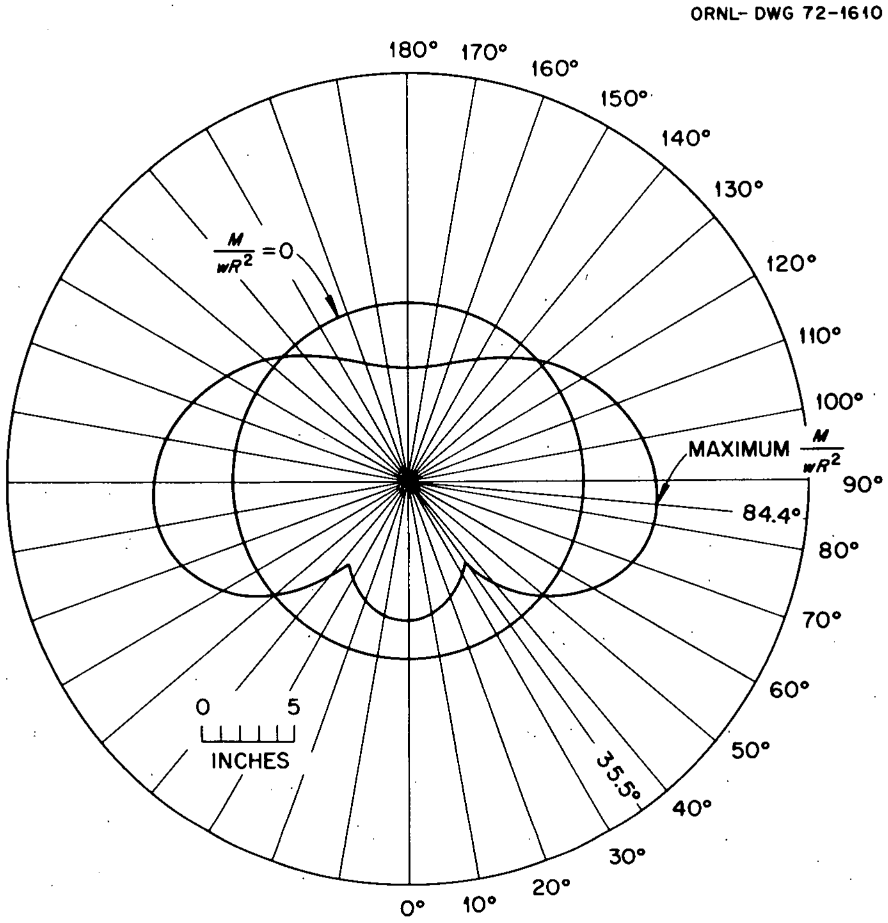


Figure 3 Polar Plot of $\left(\frac{M}{wR^2}\right)$.

d) Fracture toughness. The basic equation of fracture mechanics is

$$K_I = C\sigma\sqrt{\pi a} \,, \tag{5}$$

where K_I is the elastic tip stress intensity factor in ksi $\sqrt{\text{in.}}$, C is a non-dimensional shape factor that depends on geometry and the shape of the stress distribution over the area of the flaw, σ is the nominal stress at the location of the flaw in ksi, and a is the flaw size in inches. At fracture, σ equals σ_f the fracture stress, and K_I equals its critical value at fracture K_{Ic}, which is in effect a material property.

Equation (5) can be solved for the flaw size that would be critical at a given stress level. The result is

$$a_{cr} = \frac{1}{\pi}\left(\frac{K_{Ic}}{C\sigma}\right)^2 \,, \tag{6}$$

where a_{cr} is the critical flaw size. The critical flaw size is proportional to the square of the fracture toughness, K_{Ic}, and is inversely proportional to the square of the applied stress, σ.

Research sponsored by the HSST Program has shown that a lower bound to the minimum dynamic fracture toughness can be calculated from the equation

$$K_{Id} = \sigma_{ys}\,\frac{125}{207 - T} \,, \tag{7}$$

where K_{Id} is the dynamic fracture toughness in ksi $\sqrt{\text{in.}}$, σ_{ys} is the actual static yield stress in ksi, and T is the temperature in $^{\circ}$F. Using the minimum specified yield stress of 50 ksi provides additional conservatism, and results in a calculated value of K_{Id} of 35.7 ksi $\sqrt{\text{in.}}$ The actual value of K_{Id} at +32°F exceeds 50 ksi $\sqrt{\text{in.}}$

d) Critical flaw size calculation. Equation (6) was used to calculate a critical flaw size, on the assumption that the maximum bending stress acted over the entire area of the flaw, which is conservative. The value of C was taken as 0.9, which is accurate for relatively deep surface cracks and conservative for shallow cracks. a_{cr} is determined by the following calculation.

$$a_c = \frac{1}{\pi}\left[\frac{35.7}{(0.9)(11.6)}\right] = 3.72 \text{ in.}$$

No surface flaw with a depth less than a_{cr} would have extended during the incident. The critical size of embedded flaws would be greater. Since there is general agreement that the inspection following the incident would have detected cracks of this size, but none were detected, it can be concluded that crack extension did not occur during the let-down incident.

Conclusions

Two types of fracture analyses, both believed to be conservative, have been made for the purpose of estimating the critical size of a flaw that would have been extended by the stresses induced in the incident. In one analysis the induced stress at the vessel surface was simply and conservatively assumed to be the yield stress, and realistic values of fracture toughness were used. The smallest flaw depth calculated by this method is 2.16 in. In the other analysis the load on the vessel was first calculated on the basis of observed damage (and lack thereof) in supporting structures. Stresses thus determined were combined with conservative dynamic fracture toughness values with the conclusion that a flaw of depth less than 3.72 in. would not have propagated.

The critical size of a flaw would vary according to a location and orientation in the vessel, and in both analyses these values represent the smallest sizes with respect to this factor. It should also be noted that the yield stress levels assumed in one analysis (Canonico) are much higher than the maximum stress calculated in the other analysis.

We conclude, conservatively, that since the second on-site nondestructive examination would have revealed any flaws larger than 2 in.

in size, but none were detected, that any existing flaws would not have been extended as a consequence of the incident.

References

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2. W. O. Shabbits, W. H. Pryle, and E. T. Wessel, Heavy Section Fracture Toughness Properties of A533 Grade B Class I Steel Plate and Submerged Arc Weldment, USAEC Report WCAP-7414, Westinghouse Electric Corporation, December 1969.
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