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METALLURGICAL EXAMINATION & REVIEW
OF
CASTING DEFECTS
IN THE
STAINLESS STEEL VALVE BODIES
LOCATED IN THE CLASS ONE SYSTEMS
OF THE
OYSTER CREEK REACTOR

No. DC-31 March 3, 1969

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Metallurgical Examination and Review of Casting Defects in the Stainless Steel Valve Bodies Located in the Class One Systems of the Oyster Creek Reactor

No. DC-31

March 3, 1969

Prepared for: AEC Contract No. AT(11-1) - 1658
Task A
Parameter No. 68-69A; Subcontract No. 7

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Introduction

At the request of the Region I, Newark Office - Division of Compliance, the author visited the Oyster Creek Reactor site near Toms River, New Jersey on February 12, 1969. The purpose of the visit was to review the evaluation and appraise the repair schedule of linear defects observed in cast valve bodies which were a part of the primary and safeguards service system of the reactor.

The author was accompanied by:

Mr. R. Carlson, Senior Reactor Inspector - Region I, Newark Office-Division of Compliance USAEC

Mr. W. J. Collins-Division of Compliance-Headquarters USAEC-Washington, D.C.

Mr. R. M. Gustafson-Division of Reactor Standards, USAEC-Washington, D.C.

During the visit the following persons were contacted:

L. Loeb - GE - APED

J. W. Eberle - General Electric Company

Bob Huggins - Principle Project Engineer - Oyster Creek-GE

Nel Strand - Site Construction Mgr. - Oyster Creek

Tom McClukey - Plant Superintendent - Jersey Central Power and Light Company (Utility)

Thomas E. McSpadden - MPR Associates, Inc.

The prime contractor is the General Electric Company and their Atomic Power Equipment Department (APED) is involved. The utility is the Jersey Central Power and Light Company, and their consulting engineers are MPR

Associates, Inc. of Washington, D. C.; Burns and Roe are the architectural engineers.

The valve bodies in question are cast austenitic stainless steel, Grade CF8M, which corresponds to wrought stainless type 316. They range in size from 4-in. to 16-in. in diameter and are distributed in the following system:

1. Core Spray
2. Channel Cooling
3. Clean-up Demineralizer
4. Control Rod Return.

There are a total of 43 valves involved.

Forty (40) of the subject valves were purchased by the architectural engineers, Burns and Roe, from the Anchor Equipment Company to a specification which required that the valves be 100% inspected by radiography to class 2 of ASTM E-71. Two separate foundries, each with their own separate inspection contractors, were employed by Anchor to furnish the valve castings.

A routine visual inspection of a valve revealed that a casting defect had been uncovered during the pre-installation machining of the cast part. This prompted the review of all valves above 4-in. in size in the class one systems of the reactor. These inspections revealed that seventeen (17), of a total of forty-three (43) involved, required repairs of defects to one degree or another. It should be remembered that this review was performed on installed valves which had already been hydro-tested. Three (3) of these seventeen valves were found defective to such an extent that replacement of the valve was necessary. Three (3) other valves from this group of seventeen required weld repairs. The remaining eleven valves could be satisfactorily repaired by only surface grinding. Visual and dye penetrant inspection techniques were used to establish the integrity of all valves being reviewed.

Radiography was used to establish the as-repaired integrity.

The extent of the casting defects found and the fact that all defective valves were purchased from the same vendor (Anchor supplied forty out of the forty-three valves in question - APED supplied three) prompted a review of the original, specification radiographs submitted by this vendor. The contractor,the General Electric Company, elected to review the radiographs of only 21 Anchor valves; their selection was based on service requirements and part size. The results of these studies confirmed and supplemented the visual and dye penetrant inspections performed at the reactor site and outlined above. The valves which were, or will be, replaced were identified as:

No. V-20-41
No. V-14-34
No. V-16-2

Those valves requiring weld repair were:

No. V-20-17
No. V-17-19
No. V-17-54

A summary of the radiographic review by the General Electric personnel is attached as Exhibit A, and is the reviewer's initial statements prior to repair initiation (the replacement and weld repair outlined above was determined at a date later than this memo). A preliminary statement of initial impressions relating to the Oyster Creek site visit on February 12, 1969 was prepared by the author, and it is attached as Exhibit B.

Discussion

The valve originally detected as being defective, No. V-20-41 located in the Core Spray system, was finally replaced. Sections were taken from the defective valve and submitted for metallurgical examination. The author examined these microsections at the GE-APED laboratories in San Jose, California on February 20, 1969. Mr. Robert Dodds of the Division of Compliance - Region V - USAEC was present as we met with Mr. Loeb and Mr. John E. Leatherman of APED-GE and Mr. William R. Schmidt of MPR Associates.

A close examination of the metallographic specimens taken from the top surface of the rim was performed by the author. These sections were taken from the area of the visually observed defects and were located in both longitudinal and transverse orientations. The valve had received, prior to machining, a homogenizing treatment of approximately one-half hour at 2000°F, followed by a water quench.

An example of the defects observed in these microsections is shown in Exhibit C. This micrograph shows that these indications are a combination of microshrinkage voids and hot tears. More specifically, it appears that the microvoids (shrinkage) are essentially linked by hot tears. These defects were metallographically observed, in some cases, to be greater than one-inch in length. No evidence of excessive mold-metal reaction was metallographically observed.

A preliminary statement relating to these metallographic examinations was prepared by the author, and it is attached as Exhibit D.

A properly designed casting, a properly prepared mold, and correctly melted metal should result in a casting having no defects. However, the combination of perfectly executed events such as these cannot consistently be expected, even with the utmost in design. Thus it is not unusual for casting to have defects and particularily those which form during the solidification process. It was these types of imperfections which were observed in this case.

A hot tear is an intergranular failure (along the grain boundaries) that occurs while the casting is at a high temperature within a mold. A hot tear may form in a larger section of a casting that is at a temperature just above the solidus temperature and is subjected to tensile strains induced by the solid contraction of an adjacent, already-solidified thinner section. While the mass is just above the solidus temperature, it consists of grains of metal that are surrounded by a thin film of liquid that cannot support a tensile load. Thus, a parting of the metal grains at the grain boundaries results, leaving closely spaced, or even linked, microvoids. After the area completely solidifies, but is still near the solidus temperature, the small spaces between the microvoids often fail or crack as a result of solid contraction. Other microvoids can form from the natural contraction during solidification and areas of liquid starvation.

Therefore, the point here is not that the castings had defects in them, but that these defects were not detected and repaired. A personal review, with Mr. Collins, of the original vendor radiographs of selected valves revealed that in all cases at least the major defects (those which ultimately resulted in valve replacement or weld repair) were clearly visible.

Weld repair procedures and techniques being performed on the three valves mentioned above were found to be most satisfactory. The good practice of very low energy input, guaranteed by a low interpass temperature and a stringer-head welding technique, was being closely maintained. The welding was being performed using the tungsten-inert gas process with a bare, type 316 stainless steel filler rod.

Conclusions

Based on the above facts and observations made during the inspections performed on 12 February and 20 February, 1969, the following conclusions can be made.

1. The casting defects found in the valve bodies installed in the class one systems of the Oyster Creek reactor were metallographically determined to be the result of solidification shrinkage and hot tearing and were manifested as linked microvoids.
2. The metallographic examination revealed no excessive mold-metal surface reactions.
3. Pre- and post- heat treatment radiography indicated that these defects were truly casting imperfections, and that the heat treatment sequence did not propogate the defects.
4. The defects observed, both radiographically and metallographically, are common to the casting process. Such defects are frequently expected in designs such as these, and the fabricator usually tries to reduce their occurance by gating and risering techniques and, when required, weld repair.
5. The real point here lies in the breakdown in the control of the review and analysis of non-destructive test results. Had this situation not existed, defective parts would not have gone undected.

This fault must be borne, in a major way, by the primary valve contractor, the Anchor Equipment Company. However, it is felt that the prime contractor, the General Electric Company, and its architectural engineering firm, Burns and Roe, must jointly be held responsible for their negligence in not maintaining, by continuous review, the quality assurance of their vendor. Had the code-required procedures and specifications been properly adhered to the current problem could not have existed.

6. The procedures and techniques of weld repair of the casting defect, and subsequent nondestructive testing, are considered to be proper and correct.

7. Finally, it is considered important, if not critical, that the remainder of the Anchor valves in the primary system (totaling 19) be reviewed similar to those already examined. This statement is supported by the results of the re-examination of the other 21 Anchor valves, considering that this review caused major repairs to be required on 25% of the parts in question, which had previously been termed as meeting Code requirements.

It is the author's opinion that the General Electric people are making a reasonable effort to correct what is a bad situation, and that they have a good understanding of the problem, have performed an adequate analysis, and are aware of its cause.

EXHIBIT A

GENERAL ELECTRIC COMPANY

175 CURTNER AVE., SAN JOSE, CALIF. 95125 . . . AREA CODE 408, TEL. 297-3000
TWX NO. 910-338-0116

NUCLEAR ENERGY DIVISION

ATOMIC POWER EQUIPMENT DEPARTMENT

February 12, 1969

REPORT OF RT-REVIEW AND SITE-INSPECTION OF ANCHOR STAINLESS VALVE BODY-CASTINGS FOR PRIMARY AND SAFEGUARDS SERVICE IN OYSTER-CREEK NUCLEAR POWER PLANT

D. E. Tackett E. H. Franks
Field Applications Engineering, N.S.P.&P., GE-APED

Summary

At the request of S. Naymark, Manager, DTP Project Engineering, we have completed a review of radiographs for all stainless steel body-castings in primary and critical safeguards service at the Oyster-Creek nuclear plant. The following valves required replacement, major repair or re-radiography for the reasons noted:

- Valve V-20-41 is being replaced due to defects found during site inspection; these defects were such that a field repair was not practicable. We have reviewed and accepted the radiographs for the replacement body-casting.

- Valve V-14-34 is being replaced due to defects found during exploratory grinding of a surface indication found during site inspection; field repair would have caused distortion of the seat ring. Radiographs for the replacement body-casting will be reviewed and accepted prior to shipment of the valve body from Anchor.

- Valve V-20-17 requires repair of unacceptable defects found during RT-review of original-film in San Jose. Exploratory drilling inspection at site confirmed that field repair has very good chance of success. A replacement casting has been ordered. This valve body will be either repaired to an acceptable condition or will be replaced.

- Valve V-14-37 lacked complete RT-coverage due to two films that were missing. The portion lacking coverage consists of two areas each about 3-inches by 10-inches. These areas will be re-radiographed by the site in accordance with a shooting sketch provided by D. E. Tackett. The retake films will be reviewed by Tackett/Franks and will be filed with the original film. No repair action is anticipated due to satisfactory quality shown in adjacent radiographs.

- Valve V-16-2 had an area of unacceptable inclusions that was marked for repair on the original films. RT-review of original/repair films in San Jose failed to confirm that the repair had removed enough of the inclusion-area to result in an acceptable condition. Also, in another area of the same valve body, original films showed hot-tear indications for which retake is required to evaluate as-installed condition of the casting. The affected areas of the body-casting will be re-radiographed by the site in accordance with a shooting sketch provided by D. E. Tackett. The retake films will be reviewed by Tackett/Franks and will be filed with the original film. If repair is required (either or both areas), field repair should have a good chance of success. Based on review of partial-coverage retake-films from the site, it appears that repair of the inclusion-area will probably be required; final recommendation must await review of full coverage retakes of the questionable areas.

- Valve V-17-19 had a borderline-acceptance hot-tear indication in the original film that could not be correlated with any of the reported surface-defect repair-areas at the site. The size and location of this indication is such that an as-installed retake radiograph is required to evaluate the adverse effect of the defect on service integrity of the valve. A retake of the questionable area is being made by the site in accord with a shooting sketch provided by D. E. Tackett in telecon to K. Haynes (2/10/69). Final recommendation must await review by Tackett/Franks of site retakes.

Based on the Tackett/Franks RT-review in San Jose, all remaining body-castings were found to be acceptable by the standards of ASTM E-71, Class 2. All remaining body-castings were also found to be acceptable by liquid-penetrant inspection of the outside surface at the site; some valves required grinding or minor repair welding to remove shallow surface defects. Upon completion of the above-noted repair/re-inspection/replacement, based on the RT-review in San Jose and on the satisfactory results of liquid-penetrant inspection performed at the site, we (Tackett/Franks) consider that the subject valves have more than adequate structural soundness to fulfill all design requirements of the primary and engineered safeguards service-applications where these valves are installed.

Background

All of the subject valves were purchased by Burns and Roe from Anchor on B&R purchase order BR-2299-92 to meet the requirements of B&R specification S-2299-61. Paragraph 5.b of the latter required that body-castings for the subject valves be 100% inspected by radiography to Class 2 of ASTM E-71. The "Valve No." listed in the accompanying table is the system identification as shown on the P&ID drawing. The "Item No." listed in the table corresponds to the item number in the purchase order (BR-2299-92) and specification (S-2299-61) for the subject valves. All of the subject valve bodies are cast austenitic stainless steel, Grade CF8M, which corresponds to wrought stainless type 316. Castings for these valve bodies were obtained by Anchor from one of two foundries: Roemer or Vulcan. Castings poured by Roemer were radiographed and liquid-penetrant inspected by Conam. Castings poured by Vulcan were radiographed and liquid-penetrant inspected by X-Ray Engineering. Weld-repair of castings (when required as a result of original radiography) was performed by the foundry that poured the casting. The foundry responsible for each valve body-casting is listed under "Foundry" in the table. The foundry stamped each body-casting with the "Heat No." and "Body No." as listed in the table, which combination constitutes a serialization of each casting. Radiographs are identified to the casting by the heat/body combination. To ensure that the radiographic film reviewed was of the body-casting for the listed valve, the heat/body identification was obtained directly from the stamping on the installed valve; it is this identification which is listed under "Heat No." and "Body No." in the table. The heat/body identification so obtained exactly agreed with the radiographic film identification except for valve V-16-2 (see Note 12 of the table). In the case of valve V-16-2, the body-casting was stamped heat "4-8" body "1" by Roemer, whereas the radiographs, inspection reports, and material test reports are identified to heat "4-48" body "1"; Anchor will transmit to us a letter certifying that the body-casting stamped heat "4-8" body "1" is, in reality, heat "4-48" body "1". In addition, comparison of defects in the site-retake films with defects in the original films positively identifies the installed casting to be the same casting originally radiographed as heat "4-48" body "1".

Site Inspection

A suspicious surface-defect was noted during visual inspection of valve V-20-41 after installation at the site. Liquid-penetrant inspection of the affected area (near bonnet rim) revealed radial crack-like defects across the top surface of the rim; some of these indications continued down both inside and outside machined surfaces. Careful examination of original films in this area of the casting reveals a hot-tear into the top of the rim. Careful visual examination (at 8X) of these defects by D. E. Tackett (during site visit on 1/31/69) showed these defects to be hot tears; such defects occur on initial cool-down of the casting just below the freezing temperature. These defects should have been detected by the original liquid-penetrant inspection and rejected at that time (see below under Conclusions). The hot tear indication shown by radiography in the original film is considered to be a Class 2 borderline-acceptable condition. Due to the number and location of defects in V-20-41, field repair was not practical and a replacement body-casting was ordered. Liquid-penetrant inspection of the outside surfaces of all stainless-steel body-castings of Anchor valves in primary and safeguards applications was performed at the site. Indications which required grinding to obtain acceptable liquid-penetrant test results are reported for each valve under the column headed "No. Surface Indications Explored" in the table. Except for valve V-14-34, either no repair welding was required or only minor repair welding was needed. In the case of V-14-34, grinding and liquid-penetrant inspection revealed defects near the seat-ring weld to an extent that field repair welding would have resulted in excessive seat distortion and would have required access from inside surface; therefore, it was decided to replace the body-casting instead of attempting field repair. Three valves, V-20-12, V-20-18 and V-17-54 were selected at random from the subject valves for re-radiography at the site. These site-retake films have been reviewed by Tackett/Franks and show the same identical defects that were revealed by the original films; all defects in both original films and site-retake films for V-20-12, V-20-18 and V-17-54 are acceptable to Class 2 of ASTM E-71 (except see Note 17 regarding rejectable hot-tear in V-17-54 which was repaired prior to site retakes).

Radiography Review

Radiography films made by Conam and X-Ray Engineering of the as cast body-castings for the subject valves were obtained from Anchor for review by Tackett/Franks in San Jose. The total film-record for the subject valves consists of several thousand films (including body castings, bonnet castings, cast stems, and discs); out of several thousand film only two film (B and F on valve V-14-37) could not be located, requiring partial-retake of that valve at the site (see Summary above and see Note 10 of the table). Of the film provided, all films of the body-castings were reviewed except for radiographs of the inside throat (the inside throat of these valves does not constitute a pressure boundary and does not contribute to body strength; its function is merely to support the seat ring). Radiographs of bonnet-covers, discs, and stems were not reviewed. All indications in each film (including acceptable defects, artifacts, and surface-contour shadows) were recorded and evaluated as to relevancy, acceptability to Class 2 of ASTM E-71, and effect on the structural soundness of the casting. Each set of film for each body-casting was checked for appropriate identification (heat/body numbers) to the system valve and for overlap of adjacent exposures to ensure that full RT-coverage was obtained. The following definitions apply to the significant defects noted in the subject valve body-castings:

- Shrink. This defect consists of an irregular-shaped multiple-branched void in the metal caused by local liquid starvation during freezing of the casting. Shrink is common in and near rims, ribs and other section-changes where there is a possibility of thinner sections freezing solid while thicker sections are still partly molten; the result is blockage of flow of liquid metal from the risers into the thick section to compensate for the volumetric contraction that occurs at freezing. Since the metal freezes immediately at all surfaces of contact with the mold (due to the chill effect of the cold mold) forming a continuous skin from which the solid-metal grains grow toward the center of the thickness, shrink tends to be near the center of the section thickness and is rarely open to an as-cast surface.

- Gas. This defect consists of empty voids in the metal due to trapping of gas when the metal freezes. Gas-voids are globular (blow-holes) or elongated-round (worm-holes) in shape and are not branched. The liquid metal has a higher solubility for gas than the solid metal; therefore, considerable gas is released during freezing. If there is not an open path for this gas to escape through liquid metal out of or into a riser, the gas will remain trapped and form a gas-void in the solid metal. The same factors which promote shrink also promote gas entrapment; therefore, these two types of defects are frequently encountered together. For the same reasons as for shrink, gas voids are rarely open to an as-cast surface.

- Inclusions. This defect consists of filled voids in the metal due to trapping of mold-sand. The hot liquid metal is very erosive to the surface of the sand mold. If the metal is poured at just the right temperature and rate of flow through the mold-channels, and if the mold-sand has been properly packed, a thin glass will form on the mold surface and prevent entry of significant sand into the molten metal. Pouring of the metal either too cold or too hot, or pouring at too fast a flow rate through the mold (too slow a pour will result in internal chills), results in washing away of the surface of the sand mold; the sand thus washed away is trapped in the metal (normally in the form of a glassy inclusion or partly fused sand). Trapped sand is frequently associated with small shrinks (tails on the inclusions). Sand trapped at the metal surface results in a sand-hole.

- Hot tears. This defect consists of an intergranular separation when the metal is stressed as the casting cools down from the freezing temperature. Hot tears occur near the freezing/melting temperature. Due to composition unbalance, and also due to local composition-variation due to freezing process, all the molten metal does not freeze at the same temperature; the last metal to freeze is in the grain boundaries and freezes at the lowest temperature. If the metal is stressed during this critical temperature range (about a hundred degrees below freezing temperature), the grain boundaries will separate where still liquid, resulting in hot tears. Hot tears may or may not break through one of the skins of the casting, depending on severity and location. Hot tears are frequently found as radial cracks into rims due to the circumferential stress that results from the restraint of the mold-core; hot tears are also found in thin sections between thick sections parallel to the change in section.

- Borderline-Acceptable. This is a classification of defect-severity according to ASTM E-71 radiography standards for castings. The term in no way implies marginal strength or questionable soundness of the casting. Borderline-acceptable is merely the manner of defining the limits of acceptability of various types of defects. Any defect or combination of defects that constituted a condition approaching the limits of acceptability of ASTM E-71 was reported as "borderline-acceptable" during this review and was carefully evaluated regarding effect on the structural soundness of the casting. Any hot tear, regardless of size or location, was considered "borderline-acceptable" and carefully studied as noted above; an explanation is given in the table notes for all hot-tear indications accepted during the RT-review. Site retakes were requested for all hot tears that could have an adverse effect on service integrity of the valves. In the accompanying table, the number of borderline-acceptable conditions in each casting is reported under the columns headed "Borderline-Acceptable RT Indications". Inclusions and gas holes are combined in reporting the number of borderline-acceptable defects since such defects have a minor effect on the basic structural strength of the casting.

To the maximum extent possible, the RT-review was correlated with the results of the surface inspections performed at the site. Many of the significant defects found during the RT-review were corrected and eliminated during the site inspection; where positive correlation of RT/PT indications has been made, this is reported in the appropriate note of the table. The net result is a considerable reduction in the overall number of "borderline-acceptable" conditions remaining in the as-installed valve bodies. In addition, some re-radiography was performed at the site and the site retake-films were carefully compared to the original films to determine whether there was any significant change in the defects. Since the original films were made prior to solution heat-treatment of the castings, this comparison of site-retakes to original films constituted a comparison of defects before and after heat treatment. Radiographs of the following valves were compared to determine changes in defects that might have occurred during heat-treatment:

- Valve V-20-17: Review of original films revealed a severe shrink near the bonnet rim (this shrink was rejected by the reviewers, see Summary above); site retake films of the same area also showed severe shrink. The total length of this defect was about six-inches, including a network of multiple branches. Careful comparison of the original and site-retake films showed that the defect had not changed during heat treatment of the casting. A questionable shrink near the guide-rib in the center of the body (this indication was also rejected by the reviewers, see Note 3 of the table) showed on original films; comparison with site-retakes showed no change during heat-treatment. There were no defect indications in the retake films that did not show as identical defects in the original films.

- Valve V-16-2: Review of original films revealed an area about six-inches in diameter, near the center of the body on one side, having a high density of sand inclusions and small shrinks (this area was rejected by the reviewers, see Summary above). The same indications would have been borderline-acceptable in a thicker casting; however, as located in this casting, the accumulation of defects was considered unacceptable for the thin section between the seat-rings. Comparison of site-retakes with original films showed no change in the linear defects in this area and showed no development of additional defects. Site retakes of borderline-acceptable hot tear indications in original films are being made but are not available as of this writing (see Incomplete Work below).

- Valve V-20-18: Review of original films revealed several gas holes of moderate size, with branching small-shrinks originating from each gas hole (the combination of defects was considered by the reviewers to be borderline-acceptable to Class 2 of ASTM E-71 and are reported in the table as borderline-acceptable under "Gas Holes", even though the gas or shrink, taken separately, would not have constituted a significant defect). These defects were located near the bonnet-rim of the body-casting. Careful comparison of site-retakes with original films showed no change and no development of additional defects.

- Valve V-20-12: The single hot tear shown on original films was at top of rim and did not show on site retakes; this tear was probably removed in excess material machined from top rim during finishing of the casting. The single large inclusion shown on original films also showed identically on site retakes. Careful comparison of site-retakes with original films showed no change and no development of additional defects.

- Valve V-14-34: A minor surface indication led to excavation into the thick section behind seat ring; this excavation uncovered shrinks/tears extending to inside surface (this valve-body is to be replaced; see Summary above and see Note 7 of table). Site-retake radiographs of the excavated area showed exactly the same indications as were shown at this location on the original film; therefore, it is certain that the defects were due to the casting process and not due to heat treatment.

- Valve V-17-54: A full set of site retake films was compared to corresponding locations on the original films. Also, sketches of defects removed by grinding or repair-welding were compared to matching indications in original films. A shallow hot tear indication about 6-inches long (this should have been rejected on the original film) exactly matched the surface defect which was excavated/repair-welded at site; retake-film now show this area clear. Similarly, all other ground or repaired surface-defects found during site inspection were matched to corresponding indications on the original film. Also, minor buried defects in s'te retake films were carefully compared to same defects in original films; no change was noted nor did any additional defects develop. All of the foregoing provides strong evidence that there was no growth or addition of defects during the heat treatment process.

- Valve V-17-19: A significant hot-tear indication (borderline-acceptable) in the original film corresponds identically to a surface defect which was excavated/repair-welded at the site; the affected area is clear on site repair-retakes. This is evidence that the surface-defect originated during casting and not during heat treatment. Site retakes of another borderline-acceptable hot-tear in this valve-body are being made but are not available as of this writing (see Incomplete Work below).

In all of the above, a considerable number of linear defects were compared between original-film indications (as-cast) and as-installed indications (either liquid-penetrant or site-retake-film indications). There was absolutely no evidence of development or growth of defects as a result of solution-annealing heat-treatment which was done after original radiography. Therefore, we (Tackett/Franks) consider that the original as-cast radiographs are fully representative of the as-installed condition of the subject valve body castings with respect to evaluating structural soundness and effects of defects on service integrity.

Incomplete Work

The following work remains to be completed on the subject valves so that the body-castings will have unquestionable structural-soundness for the intended service:

- Valve V-14-34: The radiographs of the replacement body-casting have not yet been reviewed by Tackett/Franks.

- Valve-20-17: The repair/reinspection/refurbishing of the rejected/questionable areas of the body-casting are in progress; the final post-repair radiographs have not yet been reviewed by Tackett/Franks.

- Valves V-14-37 and V-17-19: The required site-retake radiographs have not yet been reviewed by Tackett/Franks.

- Valve V-16-2: The required site-retake radiographs providing full-coverage of the questionable areas have not yet been reviewed by Tackett/Franks; repair will probably be required.

Conclusions

Some discussion of the original inspection of the subject valves appears to be needed. If, as we maintain, the surface defects found at the site existed in the valve bodies from the time they were cast, why were these defects not detected and corrected at the original liquid-penetrant inspection? Also, how was it possible for radiographs to be accepted when the films showed obvious indications of clearly unacceptable defects? We feel that the following factors in the original inspection satisfactorily answer the above questions:

- Liquid penetrant inspection of castings requires carefully controlled techniques to ensure effective detection of defects. The inherent rough surface of the casting presents special problems in removal of excess penetrant prior to application of developer. The most frequent cause of loss of effectiveness for liquid-penetrant inspection of castings is over-removal of excess penetrant. Where water-washable penetrant-dye is used, excess is frequently removed by high-velocity water-jet; where solvent-dye is used, excess is frequently removed by spraying or flushing the surface with liquid solvent. Both of the above methods are very effective in removing excess penetrant from the rough casting surface; however, they are also very effective in removing the penetrant from surface defects. Such abuses are common practice where liquid penetrant inspection is performed on a sub-contract basis with no witnessing or process control by the purchaser. Also, the final liquid-penetrant inspection was performed on the raw casting; machined areas of the casting were not reinspected. Since linear defects such as shrink, buried tears, etc., are likely to be uncovered when the skin of a casting is removed by machining, liquid-penetrant inspection should be done after final machining.

- Radiography of critical castings or weldments requires independent review of the films by at least two qualified interpreters. No matter how conscientious and careful an interpreter is, it is inevitable that a few serious defects will be missed or misjudged in the course of looking at several thousand film. It is very easy for an interpreter to lose his place in a stack of film, due to an interruption, and to miss one or more films entirely. Also, errors of judgement can occur since the standards are, at best, a vague guide to acceptance. Where films are reviewed by more than one person, the probability of missing a significant defect due to human errors is reduced to essentially zero. It is not at all surprising that the original acceptance of the subject valves' radiographs, solely by the inspection sub-contractor's interpreter, resulted in overlooking or misjudging a few serious defect indications.

Valve No.	Item No.	Heat No.	Body No.	Foundry	Borderline Acceptable RT Indications			No. Surface Indications Explored	Remarks	Current Status
					Shrink	Inclusions & Gas Holes	Tears			
V-20-15	19	5-12	4	Roemer	1	1	0	0		Accepted
V-20-21	19	5-41	7	Roemer	0	0	0	0		Accepted
V-20-40	19	4-9	6	Roemer	2	2	0	0	See Note 1	Accepted
V-20-41	19	4-12	8	Roemer	4	3	1	Numerous	Valve Removed	Scrapped
V-20-41	19	1-1	-	Roemer	0	0	0	-	Replacement Valve	Accepted
V-20-12	14	5-11	5	Roemer	0	1	1	1	See Note 2	Accepted
V-20-17	21	4-7	1	Roemer	2	1	0	0	See Note 3	Repair
V-20-18	14	4-10	2	Roemer	0	1	0	2	See Note 4	Accepted
V-20-23	21	4-8	3	Roemer	2	0	1	0	See Note 5	Accepted
V-14-30	73	4-14	5	Roemer				7	See Note 6	Accepted
V-14-31	74	4-28	8	Roemer				6	See Note 6	Accepted
V-14-32	73	4-15	4	Roemer				3	See Note 6	Accepted
V-14-33	74	4-4	3	Roemer				3	See Note 6	Accepted

Valve No.	Item No.	Heat No.	Body No.	Foundry	Borderline Acceptable RT Indications			No. Surface Indications Explored	Remarks	Current Status
					Shrink	Inclusions & Gas Holes	Tears			
V-14-34	71	4-18	6	Roemer	0	0	2	1	See Note 7	Scrapped
V-14-35	71	4-22	7	Roemer	1	0	1	0	See Note 8	Accepted
V-14-36	61	4-21	9	Roemer	0	2	2	0	See Note 9	Accepted
V-14-37	61	7-20	11	Roemer	2	0	1	0	See Note 10	Retake
V-15-29	113	3232D	1	Vulcan	0	0	0	0		Accepted
V-16-1	160	5-9	10	Roemer	0	1	0	1	See Note 11	Accepted
V-16-2	161	4-8	1	Roemer	0	4	1	0	See Note 12	Retake
V-16-14	160	4-48	9	Roemer	0	0	0	1	See Note 13	Accepted
V-16-61	161	5-8	5	Roemer	0	2	0	0		Accepted
V-16-62	135	3216D	3	Vulcan	0	0	1	0	See Note 14	Accepted
V-16-63	134	5-32	7	Roemer	1	0	1	0	See Note 15	Accepted
V-17-19	48	3206D	2	Vulcan	0	5	3	4	See Note 16	Retake
V-17-54	48	3206D	1	Vulcan	3	1	1	5	See Note 17	Accepted

Note 1 - Review of V-20-40 body casting RT indicated that one film station in Band B had borderline coverage in the thick section, missing approximately 1/4" at the edge with the next band being single film. However, the general quality adjacent to the missing area together with the section thickness are sufficient to assure adequate structural soundness.

Note 2 - Reported surface defect has been repaired. Review of a full set of site retakes showed no change in original defects and no development of additional defects. The hot tear reported on original films was a short tear into top of bonnet rim; it is presumed that all or most of this tear was removed during final machining of bonnet rim.

Note 3 - Review of V-20-17 body casting RT indicated that in addition to two (2) borderline acceptable shrinks and one (1) borderline acceptable inclusion noted in results, a large unacceptable shrink was located in the bonnet seat ring area. This indication was confirmed by RT of the disassembled valve in its installed location at the site. The unacceptable defect will be repaired to an acceptable condition or valve body will be replaced. A questionable indication (possibly surface-pattern) requires retake in another part of same body-casting.

Note 4 - Reported surface defects have been repaired. The borderline-acceptable condition consisted of a combination of gas-holes and small shrinks, such that the combined defects constitute a borderline-acceptable condition. A full set of site retakes were reviewed and showed the same identical defects as the original films; there was no change in the defects and no development of additional defects.

Note 5 - The hot tear reported on original films was a short tear into the top of the bonnet rim; it is presumed that all or most of this tear was removed during final machining of the bonnet rim.

Note 6 - The RT review of these body castings was conducted in October 1968 and reported to W. M. Scott on October 17, 1968. The casting quality was acceptable to Class 2 standards of ASTM E71. The surface indications have been ground and/or repair welded as required to obtain an acceptable condition.

Note 7 - Excavation of a surface defect uncovered an area of shrink/tears that would have required repair welding more extensive that would be practicable in field; therefore, this valve body will be replaced with a new casting. Radiographs of the replacement casting are not yet available for review. The defects showed on the original film of the affected area, but the RT-indication was acceptable to Class 2 standards.

Note 8 - The single hot tear reported was in an area rejected for hot tears by original radiography and repair welded by the foundry. A small residue of one of the original hot tears was not removed. This hot tear remnant is considered to be buried in the metal thickness under the repair weld deposit.

Note 9 - One of the reported hot tears is a short tear into the top of the bonnet rim; it is presumed that all or most of this tear was removed during final machining of the bonnet rim. The other reported hot tear was in an area rejected for hot tears by original radiography and repair welded by the foundry. A small residue of one of the original hot tears was not removed. This hot tear remnant is considered to be buried in the metal thickness under the repair weld deposit,

Note 10 - The single hot tear reported is a short tear into the top of the bonnet rim; it is presumed that all or most of this tear was removed during final machining of the bonnet rim. Two exposure locations of original film could not be found; retake at site is required to provide full RT-coverage for this valve body.

Note 11 - The single surface indication explored on valve V-16-1 was faired by grinding and found satisfactory by PT without repair.

Note 12 - The valve casting heat number reported by the site for the installed valve V-16-2 was "4-8 Body 1". The film reviewed by Tackett and Franks was marked as Heat 4-48 Body 1, Verification that body marked 4-8 Body 1 corresponds to film marked 4-48 Body 1 has been made through Anchor Valve Company and will be confirmed in writing by Anchor. In addition to the four (4) borderline acceptable inclusions noted in the results, a large cluster of unacceptable inclusions were located in the body wall between the seats and up along the guide. This area may have been repaired, but repair film coverage of adjacent areas is not adequate to verify removal of the unacceptable condition. The questionable area will be re-radiographed, evaluated and repaired to an acceptable condition, if required. The reported area of hot tears consists of two short, parallel hot tears in the thin section between the seats and adjacent to the thick section into which seat ring is installed. These tears may be open to the inside surface; therefore, site retake and inside-surface examination is required to evaluate the need for repair. If these tears are found to be buried in the wall, they would be borderline-acceptable to Class 2.

Note 13 - The single surface indication found at site has been repaired to a satisfactory condition.

Note 14 - The single hot tear reported was in an area rejected for hot tears by original radiography and repair welded by the foundry. A small residue of one of the original hot tears was not removed. This hot tear remnant is considered to be buried in the metal thickness under the repair weld deposit.

Note 15 - The single hot tear reported was in an area rejected for hot tears by original radiography and repair welded by the foundry. A small residue of one of the original hot tears was not removed. This hot tear remnant is considered to be buried in the metal thickness under the repair weld deposit.

Note 16 - One of the three reported hot tears was detected as a surface indication during site inspection, excavated, repair welded, and the area re-inspected by radiography. Another of the three reported hot tears was in an area rejected for hot tears by original radiography and repair welded by the foundry. A small residue of one of the original hot tears was not removed. This hot tear remnant is considered to be buried in the metal thickness under the repair weld deposit. The third hot tear reported is adjacent to an area repair-welded by the foundry and apparently opened as a result of that repair; site retake is required to confirm that this defect was removed or to confirm (with inside/outside surface inspections) that the defect is buried in the surface (in the latter case, the condition would be considered borderline-acceptable to Class 2).

Note 17 - A full set of site retakes (made after site repairs were completed) were reviewed and compared to the original films. The three areas of borderline-acceptable shrink RT-indications were found to have been due to a surface pattern which was removed during original finishing of the body casting by Anchor. The single borderline-acceptable hot-tear indication reported in the original film was a short tear into the top of the bonnet rim; it is presumed that all or most of this hot tear was removed during final machining of the bonnet rim. In addition to the borderline-acceptable conditions reported, the original films showed a six-inch long hot-tear indication, marked "surface". This RT-indication was clearly rejectable. This hot tear was detected during surface inspection at the site, was excavated, repair-welded, and the area re-inspected by radiography. Thorough review of site-retakes showed no change in original defects (except for site repairs) and no development of additional defects.

General Note:

The borderline-acceptable hot-tears which were accepted by the reviewers (Tackett/Franks) as noted above were of two types:

- Short hot tears into the top rim of the as-cast bonnet-area of the body-casting. Much of this area is removed in final machining. Small tears that remain in this area are not considered injurious to the structural soundness and service integrity of the valve due to their location outside the bonnet-seal area.

- Small remnants of hot tears that were not completely removed during excavation and repair welding by the foundry. The tears are buried in the wall of the casting under the repair weld deposit, and therefore do not have an injurious effect on structural soundness and service integrity any more than acceptable small shrinks or acceptable linear inclusions.

Hot-tears which do not fall into one of the above categories will be (or have been) repaired, regardless of acceptability to Class 2 of ASTM E-71.

Exhibit B

TO: R. Carlson - Region I, Newark Office
Division of Compliance - AEC

FROM: R. G. Gilliland - Assistant Professor of Materials Engineering
College of Applied Science and Engineering
University of Wisconsin-Milwaukee

THROUGH: Parameter, Inc.
Consulting Engineers
Elm Grove, Wisconsin

Subject: Metallurgical Examination of Casting Defects in the Stainless Steel Valve Bodies of the Primary Circulating System of the Oyster Creek Reactor - Preliminary Statement

Dated: February 13, 1969

Introduction

At the request of Region I, Newark Office - Division of Compliance, the author visited the Oyster Creek Reactor site near Toms River, New Jersey on February 12, 1969. The following is a preliminary statement briefly outlining the initial conclusions of the metallurgical analysis of Casting Defects found in stainless steel valve bodies in the primary circulating system. All the valves in question are CF-8M (similar to type 316) stainless steel cast material and range in size to 16-in. in diameter.

Discussion

Of the forty-three (43) valves involved, sixteen (16) valves required repairs of defects which were discovered after installation in the reactor system. Two (2) of these sixteen valves were found defective to such an extent that replacement of the valve was necessary. Three (3) other valves from this group of sixteen required weld repairs. The remaining eleven valves could be satisfactorily repaired by only surface grinding. Visual and dye penetrant inspection techniques were used to establish the integrity of all valves being reviewed. Radiography was used to establish the as-repaired integrity.

The extent of the casting defects found and the fact that all defective valves were purchased from the same vendor (Anchor Equipment Company) prompted a review of the original, specification radiographs submitted by this vendor (Anchor supplied 40 of the 43 valves in question). The contractor, General Electric Company, elected to review only 21 Anchor valves; their selection was based on service requirements and part size. In all cases, at least the major defects (those which resulted in valve replacement or weld repair) were clearly visible in the original radiographs.

Conclusions

Based on the above facts and observations made during the visit on February 12, 1969, the following preliminary conclusions can be stated.

1. The casting defects found after installation, which

resulted in necessary repairs (grinding, welding, or replacement), should have been observed by the vendor during their nondestructive testing program . Thus, the quality control of the valve supplier was greatly lacking. In addition, it is felt that the contractor, General Electric, must be held responsible for their negligence in not maintaining by continuous review the quality assurance of their vendor, the Anchor Equipment Company. Had the code-required procedures and specifications been properly adhered to the current problem could not have existed.

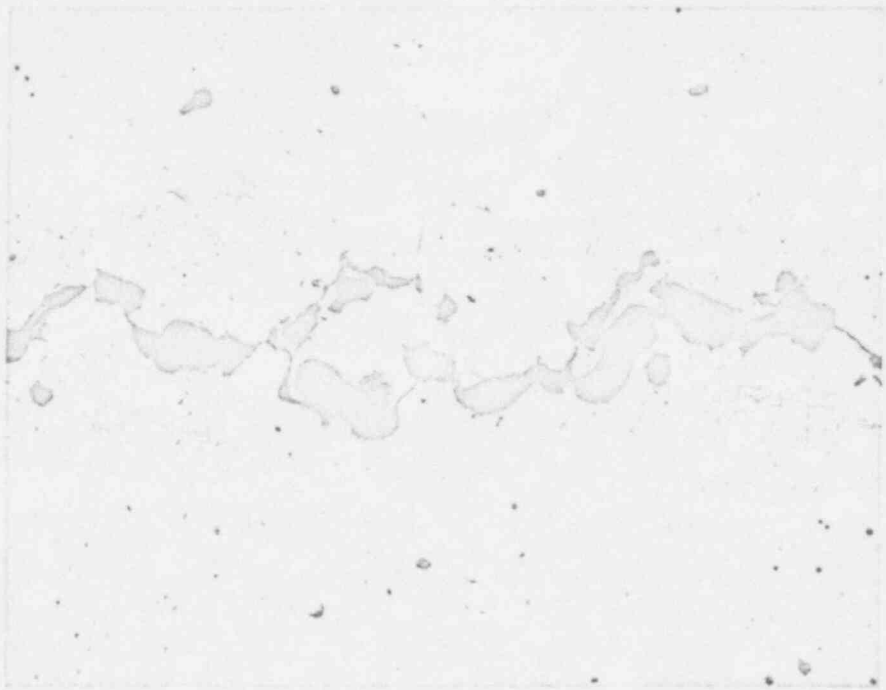
2. The procedures and techniques of weld repair of the casting defects, and subsequent nondestructive testing, are considered to be proper and correct. The good practice of low interpass temperature (200°F max.) and stringer-head technique was being employed.

3. The cause of the casting defects is suspected to be a result of solidification shrinkage, hot tearing, and/or mold-metal reactions. These very preliminary and general conclusions can only be specified as tentative until an analysis of the proposed metallurgical investigation can be made.

4. It is considered important, if not critical, that the remainder of the Anchor valves (totaling 19) be reviewed,

similar to those already examined. This statement is supported by the results of the re-examination of the other 21 Anchor valves, considering that this review caused major repairs to be required on 25% of the parts in question which had previously been termed as meeting Code requirements.

This "preliminary statement" report is made subject to revision by a more detailed document to be prepared by the author in the very near future.



Micrograph of a typical casting defect found in valve number V-20-41 during the metallographic examination performed at APED-GE-San Jose, California. Lightly etched - 250X.

The University of Wisconsin – Milwaukee
MILWAUKEE, WISCONSIN 53211

COLLEGE OF APPLIED SCIENCE AND ENGINEERING

February 25, 1969

Mr. Robert Carlson, Sr. Reactor Inspector
USAEC - Division of Compliance
Region I - Newark Office
970 Broad Street
Newark, New Jersey

Subject: Preliminary Conclusions Pertaining to the Metallurgical Analysis Performed by APED-GE on a Cast Stainless Steel Valve Body from the Oyster Creek Safety System.

Dear Bob:

As requested I visited the Atomic Power Equipment Division (APED), General Electric Company in San Jose, California on February 20, 1969. The following is my preliminary conclusions of the metallurgical analysis performed by APED-GE on a cast stainless steel valve (V-20-41) from the Oyster Creek Safety System. This valve was the first of a total of three valves to be rejected in the current reevaluation of the safety circuit valve system.

1. Three sections, taken from the top, vertical portion of valve No. V-20-41, indicated considerable micro- and macro-shrinkage voids. Some of these shrinkage voids were observed metallographically to link-up, forming what is commonly called "shrinkage cracks". These shrinkage cracks were observed, in some cases, to be greater than one-inch in length.
2. These shrinkage cracks were observed to possess blunt tips, further verifying the fact that these were shrinkage cracks rather than hot tears. In addition, this observation supported the earlier conclusion that the cracks did not proprograte during heat treatment and water quenching.

3. The defects metallographically observed are believed to be casting defects, common to the casting process. (The fact that these indications were observed in the as-cast radiographs of this valve, and other similar parts, supports the statement that these were casting defects.) Such defects are often expected in designs such as these, and the fabricator usually tries to reduce their occurrance by gating and risering techniques and, when required, weld repair.
4. The breakdown in the control of the review and analysis of non-destructive test results is the principle reason for defective parts such as these being undected. This fault must be borne, in a major way, by the primary valve contractor, Anchor Equipment Company; however, the absence of backup review by the General Electric Company must be considered, and at least a portion of the responsibility be placed with reactor contractor.
5. Finally, it is my judgement that the G.E. people have a good understanding of the problem, have performed an adequate analysis, and are quite aware of its cause.

Best personal regards.

Very truly yours,

R. G. Gilliland

R. G. Gilliland
Assistant Professor
Materials Department

RGG:jlm

cc: Mr. Richard A. Lofy - Parameter, Inc.
Mr. G. W. Reinmuth - AEC - Washington, D. C.