U. S. ATOMIC ENERGY COMMISSION
REGION III
DIVISION OF COMPLIANCE

May 31, 1967

CO REPORT NO. 10/67-4

Title: COMMONWEALTH EDISON COMPANY
LICENSE NO. DPR-2

By: H. D. Thornburg, Senior Reactor Inspector H. D. Thornburg

SUMMARY

Commonwealth Edison (CE) has essentially completed the first phase of the investigation of cracks and defects in the small diameter primary system piping. They have concluded that the small diameter piping weld heat affected zones were sensitized by the welding procedure and methods of welding application used. Stress corrosion attack then occurred in the grain boundaries of the sensitized regions. The welding procedures used in the fabrication and erection of the large diameter primary system piping should not have been conducive to similar sensitization of the weld heat affected zones.

The available records of material chemical and physical properties, fabrication records, welding procedures, metallurgical test data, etc. tend to support CE-s conclusions. The opinions of staff metallurgists and our consultant also tend to support CE's conclusions.

CE personnel have pointed out that stainless steel piping has never been known to fail in a brittle manner. The material in the heat affected zones of small diameter piping containing cracks has been shown to be ductile. Our consultant concurs in this also.

The Dresden 1 leak detection procedure and the line break emergency procedure have been reviewed and strengthened. A reanalysis of the full spectrum of line break accidents for Dresden 1 is in process.

Work is progressing toward further metallurgical examinations. Efforts are being made to obtain the detailed chemical and physical data on the small diameter piping.

A successful hydrotest of the primary system at 1205 psig and 210°F was wittnessed by Region III personnel.

No items of noncompliance or immediate safety significance were noted.

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DETAILS

I. Scope of Visit

This report has been prepared to summarize the results of our review of Commonwealth Edison's investigation of cracks in the small diameter primary system piping at Dresden 1. CO Reports No. 10/67-2 and 10/67-3 plus this report should describe the Region III effort to investigate the matter to date.

A visit was made by the writer to the CE offices in downtown Chicago on April 4, 1967 to review the available records pertaining to the primary piping material and fabrication. A visit was made to the site by the writer, Mr. C. E. Jones, Reactor Inspector, Region III, and Mr. G. Fiorelli, Reactor Inspector, Region III to wittness the hydrotest, review procedures, and obtain information on May 17, 1967.

During these visits, records were reviewed, operations in progress were observed, and interviews were held with the following Commonwealth Edison personnel:

W. B. Benke, Assistant to the President
E. C. Bailey, Chairman, Dresden Review Board
H. K. Hoyt, Superintendent, Dresden Nuclear Power Station (DNPS)
C. B. Zitek, Assistant Superintendent, DNPS
R. Holyoak, Technical Group Supervisor, DNPS
W. E. Kiedaisch, Chemist and Radiation Protection Engineer, DNPS

II. Results of Visit

A. Results of Commonwealth Edison's Investigation of Primary System Pipe Cracks

Mr. Bailey stated that the Commonwealth Edison (CE) investigation of the cracking noted in the heat affected zones of welds in the small diameter piping[1] of Dresden 1 has disclosed the following:

1. The small diameter piping became sensitized during the welding process.

2. Stresses were present in the seamless tubing due to the manufacturing process and possibly from the welding procedure used.

3. The above two conditions are necessary for initiation of stress corrosion attack. (In most cases, intergranular attack mechanisms include the presence of an ion such as Cl^-. (Writer's note)

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[1] The small diameter piping referred to above is Grade 304 stainless steel seamless tubing, ranging from 3 to 10 inches in diameter, manufactured by Babcox and Wilcox Company.

[redacted]

Results of Visit (continued)

4. The large diameter piping[2] had a known fabrication history which was not conducive to sensitization in the heat affected zones of the welds. For this reason and because a UT examination of a representative number of the heat affected zones of large diameter pipe indicated no defects, it is CE's conclusion that the large diameter pipe will not be subjected to a similar attack.

B. Independent Review

The writer reviewed the following sources of information in connection with Mr. Bailey's arguments regarding the condition of the Dresden 1 primary system piping:

1. Written welding procedures used by Southwest Fabricating and Welding Company (SW), Inc. of Houston, Texas, the firm which performed the shop fabrication of both the large and small diameter piping.

2. Minutes of meetings held between representatives of General Electric Company and Southwest Fabricating and Welding Company regarding the welding and fabrication of the Dresden 1 primary system piping.

3. Selected original radiographic films of the Dresden 1 piping.

4. Chemical anslyses, destructive test data and weld qualifications for the large diameter piping supplied by Taylor Forge and Pipe Works (TF) of Chicago, Illinois.

5. Previous reports pertaining to the problem; CO Reports No. 10/67-1, 10/67-2, and 10/67-3.

6. The invoice for the shipment of seamless tubing from the B&W Co., including heat numbers. The certified chemical analyses were not included.

7. A report prepared by the General Electric Co. titled: "Investigation of Stainless Steel Pipe Failures at DNPS No. 1, APED-5170."

8. Miscellaneous correspondence from contractors and subcontractors concerning the erection and fabrication of the primary system piping.

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[2] The large diameter piping referred to above was manufactured from rolled and seam welded stainless steel plate pipe manufactured by Taylor Forge and Pipe Works ranging from 12 to 22 inches in diameter.

Results of Visit (continued)

9. The results of meetings between Commonwealth Edison personnel and General Electric welding engineers responsible for the fabrication of Dresden 1 primary piping.

10. Various positive prints of macro and micro sections of welds and weld heat affected zones.

11. The chemical analyses for the fittings and castings used in the primary system fabricated by Bonney Floyd, Inc. of Columbus, Ohio.

12. System piping prints and details.

The results of this review corresponding to the arguments advanced by Mr. Bailey are listed below. The information identified by lower case letters and as notes was obtained from the above review.

1. The small diameter piping became sensitized during the welding process.

   a. The material (pipe and fittings) was fabricated from Grade 304 stainless steel. It is known that this material can become sensitized by the formation of chromium carbides in the grain boundaries.[3/]

   b. Mr. Chyle, our welding and metallurgical consultant, has previously advanced the observation[4/] that the macro photographs of weld cross section showed evidence that several tungsten inert gas passes (TIG) were made in applying the weld. This would indicate that high interpass weld temperatures had been experienced during application of the small diameter welds.

   NOTE: Chromium carbide takes place when stainless steel is heated in the sensitizing range of 900 to 1400°F. A narrow strip of base metal near the weld bead is heated into the sensitizing range during welding and becomes susceptible to intergranular attack.[5/]

   c. Photomicrographs of samples taken from the first two small diameter pipe failures at Dresden 1 are shown in a G-E report titled: "Investigation of Stainless Steel Pipe Failures at DNPS No. 1.[6/] Electron micrographs of one of the

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3/ Stainless Steel Information Manual, DP-860, Vol. 1, paragraph 3.2.2.
4/ CO Report No. 10/67-2.
5/ op. cit.
6/ APED 5170.

Results of Visit (continued)

cracks are shown in the same report. CE personnel stated that the photomicrographs do not indicate gross precipitation of chromium carbide, while the electron micrographs show distinct evidence of carbide precipitation. G-E personnel have indicated that they feel that the above indications do not conclusively prove that sensitization has taken place.

d. The welding procedure for the small diameter welds has been reviewed. TIG processes were specified for each pass of the weld. The weld was qualified.

NOTE: Weld test tensile data indicates that the pipe may have been cold worked to a degree. Room temperature tensile tests[7] on parent metal near crack No. 1 showed similar cold working, e.g., ultimate strength ~84 Ksi and elongation ~40%.

e. No material certification data was yet available on small diameter tubing.

f. It was noted that SW wrote Bechtel on August 8, 1958 and stated that the small diameter pipe would be sent to an outside concern for removal of asphalt substance on the outside of the pipe. It is known that the piping system received an acid wash following erection.

2. Stresses were present in the seamless tubing due to the manufacturing process and possibly from the welding procedure used.

a. A certain amount of cold working is inherent in the manufacture of seamless tubing which has not received heat treatment following manufacture. Although the manufacturing history of the seamless tubing has not been completely developed, it is believed that the tubing did not receive a post fabrication heat treatment.

b. Weld tensile test data and destructive tests performed on parent material near the first crack detected in C loop tend to support the conclusion that the seamless tubing was cold worked (see item 1.d above).

c. The GE welding engineer responsible for the Dresden 1 piping described the implementation of the welding procedure. The welds in the small diameter piping were applied by a team of two welders. In many cases the beads overlapped which was conducive to overheating and stressing.

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7/ Stainless Steel Information Manual, DP-860, paragraph 3.2.2.

Results of Visit (continued)

3. The above two conditions are necessary for the initiation of stress corrosion attack.

NOTE: There are instances where the presence of Cl^- contributes to intergranular attack at the grain boundaries. Instances of Cu^{++} ion contributing to intergranular attack have also been reported, according to Mr. Chyle.

a. The average concentration of Cl^- ion in the primary system during the year 1963, 1964, 1965 and 1966 has averaged ~ 0.04 ppm.[8/]

b. The Cu-Ni feed water heater and condenser tubes have undergone corrosion. The best data available indicates that the concentration range for Cu^{++} in the primary system has been 0-20 ppb. over the same four year period. Other corrosion product average concentrations in the primary system are:

Fe @ 20-900 ppb.
Ni @ 30-550 ppb.

4. The large diameter piping had a known fabrication history which was not conducive to sensitization in the heat affected zones of the welds. For this reason and because

a. The mill data on the plate for the large diameter pipe indicates that the plate was in the annealed condition following forming, seam welding, and solution heat treatment at TF. The yield strength of a test sample was 39,600 psi, the tensile strength was 82,710 psi, and the elongation in 2" was 58.0%. The destructive test data across the seam welds indicated <10% cold working.

b. The large diameter pipe was heat treated at 1950°F for 1 to 2 hours, depending on the thickness of the plate and cooled by forced air following forming and welding.

c. Certain of the 16" pipe sections were returned to TF by SW for removal of scale by pickling. Reportedly, precautions were taken against overexposure to HCl.

d. The shop welding procedure for the large diameter pipe contained the following elements:

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8/ This is an estimate based on summary information and does not represent an exact average of the analytical data.

Results of Visit (continued)

(1) The root pass was deposited using the TIG process. A space was left in the weld preparation so that the root pass could be observed for proper fusion and penetration.

(2) All succeeding passes were applied using the TIG process.

(3) The G-E welding engineer responsible for the Dresden 1 primary system piping stated that a spray ring water header was used inside the large diameter pipe for cooling purposes while the circumferential shop welds were applied. The inspector has found a reference to the possible use of artificial cooling methods in a document which reportedly summarized several meetings between G-E, TF, and Bechtel personnel concerning pipe fabrication. The G-E welding engineer responsible for the Dresden 1 piping reported to Mr. Bailey that a spray ring header and a system of dams in the piping were used to cool the large diameter pipe as the passes following the first two passes were applied.

(4) The use of Temple sticks sensitive to temperaures of < 800°F at pipe walls during application of large diameter circumferential welds. It was specified that surface metal temperatures be maintained below 800°F.

e. Mr. Bailey stated that he followed the field welding of the large diameter pipe.

(1) Root pass was applied using the TIG process under observation.

(2) Succeeding passes were applied using stick electrodes to maintain low interpass temperatures.

(3) Bechtel personnel made the field welds.

f. Mr. Bailey summarized his arguments with respect to the sensitization of the large diameter pipe as follows:

(1) The ~ 3/4" to ~ 1-1/2" walls of the large diameter pipe provide a more extensive heat sink than for the thinner walled pipe.

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Results of Visit (continued)

(2) In the case of the shop welds, artificial cooling was used. Temperature sensing (gross) was employed by use of the Temple sticks.

(3) Interpass overheating was avoided in the application of the large diameter field welds by the use of stick electrode passes.

(4) No cracks have been detected in the large diameter piping.

C. Hydrostatic Test

On May 17, 1967, the Dresden 1 primary system was hydrotested at 1205 psig and 210°F. The portions of the system tested were as follows.

1. The primary side of all four recirculating loops, including the 6" diameter bypass loops around the inboard steam generator outlet isolation valve, where a significant number of the defects and cracks in the small diameter piping have been found.

2. The pressure vessel and the communicating risers and downcomers to and from the steam drum. The steam drum was also pressurized.

3. The 6" downcomer header equalizing line, where defects were also found and which was subsequently replaced.

4. The small diameter piping to the first isolation valves for the following systems:

   a. Emergency condenser.
   b. Both reactor cleanup loops.
   c. Both shutdown cooling loops.
   d. Reactor drains.

5. The poison system.

6. The control drive system back to the block valves.

7. The primary steam lines to the containment isolation valves.

Two groups composed of representatives from Region III, Traveler's Indemnity Company, and CE toured all of the reactor compartments for a visual inspection of the primary system piping under 1205 psig, including:

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Results of Visit (continued)

1. Each steam generator.
2. All instrument rooms.
3. Both reactor cleanup loop compartments.
4. The steam drum compartment.
5. The vicinity of the poison tank.
6. The downcomer and riser cavities.
7. The steam line tunnel.
8. The sub pile room.
9. The vicinity of the control drive piping manifolds.

During the course of the above visual inspection, several valve packing leaks and one drum level sensor leak were detected. No piping leaks were detected.

It was observed that CE and Traveler's Indemnity personnel were very thorough in their inspection efforts. The hydrotest was considered successful by personnel at the site.

D. Safety Analysis

The CE analysis of the significance of the cracks and defects found to date in the small diameter piping is as follows:

1. The mechanism for the occurrence of pipe cracks in the small diameter piping is thought to be fairly well known and cannot be identified at present as an indication of the impending failure of the large diameter pipe.

2. The parent material at the ends and edges of the crack is ductile, which tends to preclude the possibility of a rapidly propagating brittle fracture.

3. The propagation of cracks in stainless steel is a rather slow process, which can be detected far in advance of the existence of a catastrophic primary system leak.[9]

4. Present leak detection methods employed at the site are sensitive. (See Section E below.)

5. Emergency procedures are in existence for coping with a primary system leak.

It should be noted that studies performed by G-E have shown that the double ended break of a 4" primary system line (which is not isolatable) is the maximum sized break which can be tolerated with the loss of off-site power.

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[9] Messrs. Chyle and A. Holt of DRS generally support this statement.

Results of Visit (continued)

E. Leak Detection

The writer performed a study of the Dresden 1 leak detection scheme in May, 1966, which is attached as Appendix A. It should be noted that the activity detection methods are the most sensitive (~2 to 20 cc/min with primary system activity in the vicinity of 1 μc/cc). The humidity detection system, ventilation continuous particulate monitor and containment vessel activity monitors are continuous and alarm in the central control room.

The leak detection procedure has been updated in Operating Order 6-67 by personnel at the site and was reviewed by the inspector on May 17, 1967. Essentially, it states that operation of the reactor will be discontinued if the leak is not isolatable and the airborne activity in the containment reaches 1.5×10^{-8} μc/cc, which roughly corresponds to a leak rate of 40 ml/min. Specifications for the availability of instrumentation are now included in the procedure, which are considered to be adequate by the writer.

F. Follow-up Items

As of the date of this report, the following items have not been fully pursued essentially either because of the unavailability of records or the necessary laboratory work has not yet been completed:

1. The certified chemistry of the small diameter seamless tubing. At present G-E and B&W are attempting to locate the records.

2. The physical properties of the small diameter seamless tubing G-E and B&W are also attempting to locate these records.

3. The metallurgical study of the first axial crack. G-E is presently working on this in their hot laboratories.

4. Micro probe analysis of a cracked section of small diameter piping in an attempt to identify ions which may have assisted the grain boundary attack. Arrangements have been made with Battelle Memorial Institute to perform a micro probe analysis.

5. Re-examination of all of the available radiographs of primary system welds. This work will require correlation of film identification with print weld numbers followed by an examination of the films.

These matters as well as the general performance of the leak detection scheme and the primary system piping during future service willl be followed closely.

Attachment: Appendix A