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Abstract

Many aging utility and industrial boilers are beginning to show signs of approaching the end of their useful life. One of the most obvious indications is the appearance of cracks in. the major pressure retaining components.

The boiler condition assessment is presented in this paper which illustrates the importance of condition assessment programs in detecting and evaluating potential serious incidents of pressure part cracking. This paper will describe the condition assessment program used to discover, quantify and then assess the damage to the boiler with a focus on the headers and steam drum. Key elements in the inspection program which provided data for the condition assessment include: surface replication, ultrasonic thickness and shear wave testing, destructive tube sample metallurgical analysis, magnetic particle testing and eddy current crack depth measurement.

The detailed discussion of the inspection methodology used to quantify the cracking will include an overview of the field application of eddy-current techniques. Included in this paper is a description of a data reduction and condition assessment process which provided the basis for determining the future operating limitation on the boiler.

*Finally, the paper will present operational and inspection . and testing recommendations which were necessary to ensure continued safe and reliable operation of **the boiler, given the condition** of the steam **drum.** A discussion of the relationship between boiler operation **and the boiler design will be presented to illustrate the probable cause** of the header and steam drum cracking. A brief presentation of the final assessment of **the entire boiler will also be** given.*

INTRODUCTION AND BACKGROUND

As part of a contemporary corporate strategy to provide its customers with reliable and competitively priced electric service, PSI Energy Inc. embarked on a mission several years ago to investigate the condition of its major power plant components at the older generating stations. Utilizing the data and information obtained by these investigations along with the knowledge obtained from reviewing the historical records of operations and maintenance, PSI Energy Inc. is in the process of developing a project listing with estimated timetable for each task which would minimize the risks of major component catastrophic failures. This mission is called "Engineering Condition Assessment Program (ECAP)". After the initial investigation of the unit, the ECAP provides for a monitoring system to assess changes in equipment operation and to provide the optimum replacement/repair scenarios. Replacement of components ideally should be performed just prior to a failure or before the component becomes uneconomical to operate.

Due to the economic and regulatory environment on new generation today, PSI Energy Inc. is diverging from the "old" accounting method to a better, sounder method which uses the generating station and its facilities as long as it is safe, economical and reliable. The Engineering Condition Assessment Program offers PSI's management many attractive features: status of equipment condition, prioritized project listing, budget and cash flow estimates and recommended re-evaluation period.

The development of an ECAP includes six phases. This approach provides the flexibility for PSI Energy to adapt to unit specific goals and objectives. These six steps are:

1. Statement of PSI Energy's goals and objectives.
2. Prioritization of major plant components to be inspected.
3. Inspecting, testing and evaluating results.
4. Economic analysis of the proposed projects.
5. Implementation of the recommended projects.
6. Periodic review of the operation and maintenance records for potential re-evaluation or retesting on plant equipment.

In conjunction with step 3 of PSI's Engineering Condition Assessment Program, Riley Stoker was authorized to perform a team inspection and condition assessment of the Unit 5 boiler at the Wabash River Generating Station. PSI is using the findings and recommendations contained in the final reports of the program to repair the unit in accordance with the final three steps of PSI Energy's ECAP program. Riley's practical approach to boiler condition assessment provided PSI the expertise and experience of a major boiler manufacturer and OEM in a cost effective manner.

The Riley Stoker boiler condition assessment program was initially formulated and introduced in 1985, and is described in Reference 1. This paper presents a direct application of the Riley program with special emphasis on how a utility, PSI Energy in this case, functions as an active participant in the data collection and inspection effort.

CONDITION ASSESSMENT PROGRAM

The objectives of this boiler condition assessment study on Wabash River Generating Station's Unit 5 were:

* To Inspect, evaluate and assess the current condition of the boiler and its auxiliaries,
* To establish the immediate and future maintenance activities,
* to establish a budgetary cost for the larger maintenance and capitalized projects.

PSI Energy's Wabash River Generating Station's Unit 5 is a Riley Stoker pulverized coal fired boiler (see Figure 1) with a rated capacity of 850,000 pounds of steam per hour at a design pressure of 2075 psig and a steam temperature of 1000 °F superheat and 1000 °F reheat steam with a throttle pressure of 1850 psig. Pulverized coal is supplied by three single ended ball tube mills feeding twelve (12) new Riley CCV Low Nox burners (Reference 2). At rated steam flowrate, the unit generates 125 megawatts of electrical power. This unit was commissioned in 1955 and has been successfully operated over the past 36 years.

The Riley/PSI boiler and equipment condition assessment program was comprised of the following key elements:

* Pre-Inspection Planning
* Review of Documentation
* Inspection
* Nondestructive Testing
* Destructive Testing and Metallurgy
* Expended Life Analysis
* Reporting

The equipment condition assessment tasks, for critical boiler pressure components, as described in this paper are essentially a combination of the Level 2 and 3 assessments as defined by EPRI (Reference 3). The analytical program utilized the detailed information obtained from operating records, recent steady state and transient operating data and inspection reports.

Pre-Inspection Planning

Pre-Inspection planning was a very important factor in implementing this condition assessment program. PSI Energy began planning for the program by developing and issuing a comprehensive inspection specification a full 10 months prior to the actual on-site inspection. The specification enabled PSI Energy to combine their in-house inspection capability with Riley's OEM experience and design expertise through the competitive bidding process to help minimize cost. PSI Energy Inc chose to split the inspection activities among Riley Stoker, PSI Energy and metallurgical vendors to utilize manpower and lower the overall cost of the condition assessment program. As a result of PSI Energy's planning, the condition assessment responsibilities were divided as shown in Figure 2.

Although PSI Energy retained responsibility for the non-destructive testing work, Riley, through numerous correspondence and telephone conversations, helped to determine the actual locations for the testing. The locations provided to PSI Energy, were chosen based on Riley's operating and inspection experience with similar units. Additionally, locations for access into headers and spray nozzles/liners were specified for internal fiberoptic inspections.

Review of Documentation

During the inspection, the Riley inspection team reviewed operational, maintenance, outage, failure analyses, and previous testing documents and records to establish a history of the boiler.

Inspection

A detailed visual inspection was performed on all regions of the boiler and portions of the fuel burning equipment. As part of these visual inspections, a fiberoptic inspection was performed on the internal surfaces of various headers to check for deposits and possible cracking.

Nondestructive Testing

A variety of nondestructive testing,as shown in Figure 3, were utilized to gather information on the condition of the pressure parts. The following is a brief discussion of each method and how the results were incorporated into the condition assessment.

Thirteen (13) surface replicas were used to examine the microstructure of selected pressure parts for graphitization, spheroidization, creep voids and microcracks. Ultrasonic shear wave examinations were performed to locate and measure lamination in component walls and welds. Ultrasonic tube thickness measurements were performed at selected locations in the furnace, superheater and reheater to check the integrity of the pressure boundary and obtain data for input to remaining life calculations. Magnetic particle examinations were performed to determine the presence of any indications or cracking on the external surfaces of selected pressure parts. Eddy current injection technique was used to quantify the depth of the cracks found in the steam drum.

Destructive Testing/Metallurgy

A total of eleven tube samples were removed from the boiler for metallurgical analysis. This analysis was used to check for evidence of thinning, swelling, overtemperature and material degradation in the form of graphitization or spheroidization. An additional chemical analysis was performed to verify the tube material and quantify the composition of the I.D. and O.D. deposits.

Inspection and Testing Findings

During a review of the control room charts, a significant feedwater thermal transient was discovered. During unit startup and shutdown, temperature transients in the economizer were noted to change up to 300 °F in two to four minutes.

During the early stages of unit startup, feedwater flow was interrupted periodically. Once the economizer inlet header temperature reached approximately 550 °F, feedwater flow was suddenly initiated. The sudden drop in economizer inlet header temperature induced a significant thermal shock to the header. This cycle was basically repeated two to five times during each startup creating a "saw-tooth" appearance on the economizer inlet temperature charts. Also from the documentation review, the number of startups and shutdowns could be determined and used as input to the fatigue analysis described later in this paper.

Tube bore hole cracking was noted in the steam drum and the intermediate economizer header, most likely the result of the thermal transient described above. The cracks in the steam drum were easily visible to the naked eye and located directly beneath the feedwater inlet nozzles.

A commercially available eddy current inspection technique was used to quantify sizes and depths of selected cracks. The selected cracks had to be of adequate size for the eddy current technique to yield accurate results. Figure 4 shows the distribution of the measured crack depths. Figure 5 shows the distribution of the cracks along the bore holes in the steam drum.

In addition to the eddy current testing, replicas of selected cracks were taken. Microscopic examination of the replicas revealed intergranular stress corrosion cracking and normal carbon steel microstructure. Additional replicas were taken of the following components:

1. One replica at the O.D. surface of the steam drum near the downcomer releaser tube attachment weld. Replica revealed evidence of small intergranular stress corrosion cracks in the Heat Affected Zone (HAZ) of the steam drum.
2. Three replicas on the O.D. surface of the radiant reheat outlet header. A network of intergranular cracks were noted in two replicas taken at tube to header attachment welds. In addition, creep related microvoids were found in all three replicas.
3. Three replicas on the O.D. surface of the high temperature superheater outlet header. Creep related

microvoids were noted in all three replicas.

4. Two replicas on the O.D. surface of the high temperature reheater outlet header. Creep related microvoids were noted in both replicas.

In an attempt to further define the cracking in the steam drum, ultrasonic shear wave examinations were performed. Due to the geometry of the tube bore holes and welds, no accurate information was obtained. However, numerous subsurface laminations were found in the drum metal during these attempts. Other components where ultrasonic shear wave exams were performed:

1. High temperature superheater outlet header at both outlet tee connections.
2. High temperature reheater outlet header at both outlet tee connections.

Tube samples were removed from the boiler and a metallurgical analysis performed. The following list indicates the areas from which the samples were taken and the major findings of the analysis:

1. Furnace waterwalls - fireside portion of the tube showed signs of slight overheating.

2. Radiant and high temperature reheater - Minor creep damage noted in all samples. Radiant portion had "alligator hide" O.D. indicating exposure to severe corrosion atmosphere.
3. High temperature superheater - Minor creep related damage in all samples.

Visual inspection of the outlet tubing of the convection reheater revealed external cracking and exfoliation of tube metal. Some of the exfoliation left gouges in the tube up to 1/8" deep. Most of the damage was located in the vertical run of the tubing, however, some damage was also noted on the last horizontal run. The damage was located near a retractable sootblower with the bulk of the cracking centered around an area of the tubing which was the closest to the sootblower.

All of the inspection and testing findings were presented to the designated PSI Energy representative on a continuous basis throughout the inspection. This immediate feedback allowed PSI Energy to immediately address any significant findings and remain informed about the progress of the program.

Analytical Tasks

All of the pertinent inspection findings discussed above were gathered and combined with several analytical tasks in order to completely evaluate and provide a condition assessment for selected critical pressure retaining components. The first analytical task was the development of thermal transients for use in finite element models of the economizer inlet header and superheater spray liners. The basis for the transients was the record review, pressure, temperature and flow rate information gathered from control room data.

The next task combines the results from the thermal transient analysis with component geometry and stress indices, thermal bending moment values, and operating pressure and temperature histories for use as input to a fatigue analysis. Riley's Fatigue Damage Evaluation Computer Code was utilized for this evaluation. Fatigue usage factors were calculated for the economizer inlet header and the superheater spray liners which were found to be normal for a 36 year old unit.

Creep analyses were performed for the following high temperature components:

1. High temperature superheater outlet header
2. High temperature reheater outlet header

3. Primary superheater outlet header

Riley Stoker's Creep Damage Evaluation Computer Program was utilized for this analysis. Inputs to the computer models consist of component geometry and operating history from control room data and information provided by PSI Energy personnel. Results of this analysis indicated that a portion of the creep rupture life of these components had been expended. The life expended was shown to be normal for a 36 year old unit.

Component Assessment and Recommendations

Finally, the results of the analytical tasks were correlated with the inspection findings to provide a current assessment of the applicable components. The unit was determined to be in fair condition considering the 36 years of service. There are specific areas which need repair and/or further inspections and testing to ensure that the boiler can be operated efficiently and reliably. A primary concern was the condition of the steam drum. Specifically, during the 1992 boiler outage, PSI (per Riley recommendation based on analytical evaluation and past experience, reference 4) will machine a chamfer on the tube openings into the steam drum to remove the sharp edged stress concentrations at the corner of the tube bore holes and contributing to the cracks. At the same time, a boat sample will be taken in the area of the feedwater inlet to assess the material condition of the steam drum. Finally, PSI Energy will continue to inspect, map and evaluate the rate of crack growth, if any.

The cause of the steam drum cracking was most likely thermal fatigue due to the severe temperature transients during unit startup and shutdown. Exacerbating the problem may be the relatively short length of tubing between the steam drum and downcomer header and the boiler division wall header, which results in inadequate tube flexibility, see Figure 6. As evidence, the bore holes which contain the most cracks are those attached to the straight piece of tubing extending from the steam drum to the boiler division wall header. Future inspection activities should include an internal inspection of the downcomer header and the division wall header for ligament cracking.

During the assessment of the radiant reheat tubing, it was discovered that the tube wall wastage rate indicated that replacement of the tubing would have to be performed sometime within the next ten years. The "alligator" hide appearance of the O.D. surface, U.T. thickness data and metallurgical analysis combined to estimate a replacement date of 1998 for the tubing.

SUMMARY

The success of any extensive condition assessment program depends on planning, execution and the proper application of current inspection technologies. The planning which went into the development of the ECAP by PSI Energy ensured that sufficient data was available prior to and during the inspection period. This data created an effective vehicle to make proper decisions in the latter stages of the ECAP. Further advantage to this type of formal planning, is the ability to create a living program which can be refined based on experience. The blending of the two condition assessment programs (OEM and utility) produced a quality assessment report which enabled PSI Energy to develop major capitalized projects over the next decade and to schedule further inspection and testing of the boiler with special emphasis on the steam drum.

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4. Holbrook, B.P. and King, J.P., "Recent Experience in the Inspection and Assessment of Boiler Header and Steam Drum Cracking"; presented to the Third Conference on Fossil Plant Inspection Sponsored by Electric Power Research Institute and Baltimore Gas and Electric Company, August 13-15, 1991. Riley Stoker Publication No. RST-98.

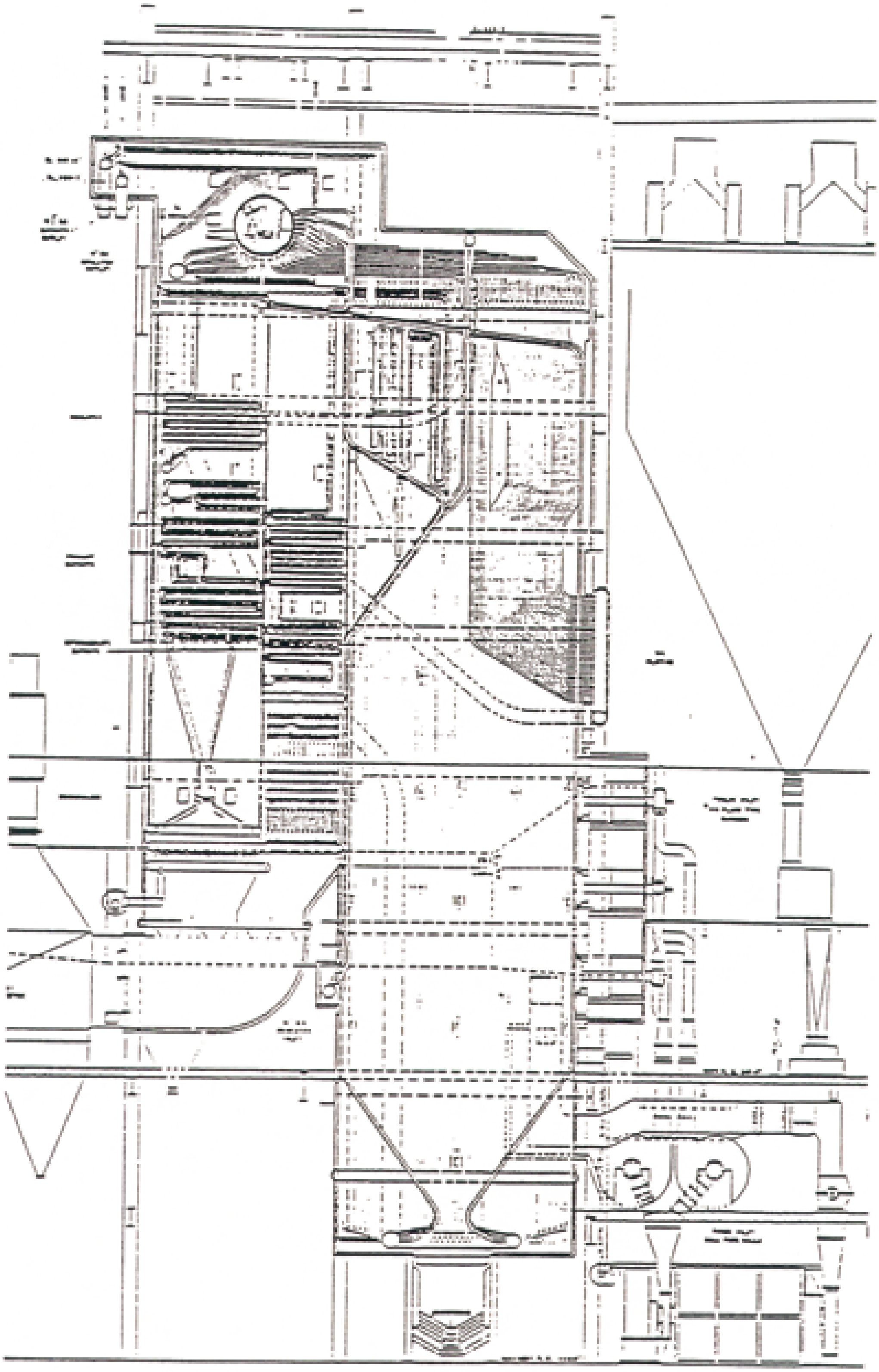
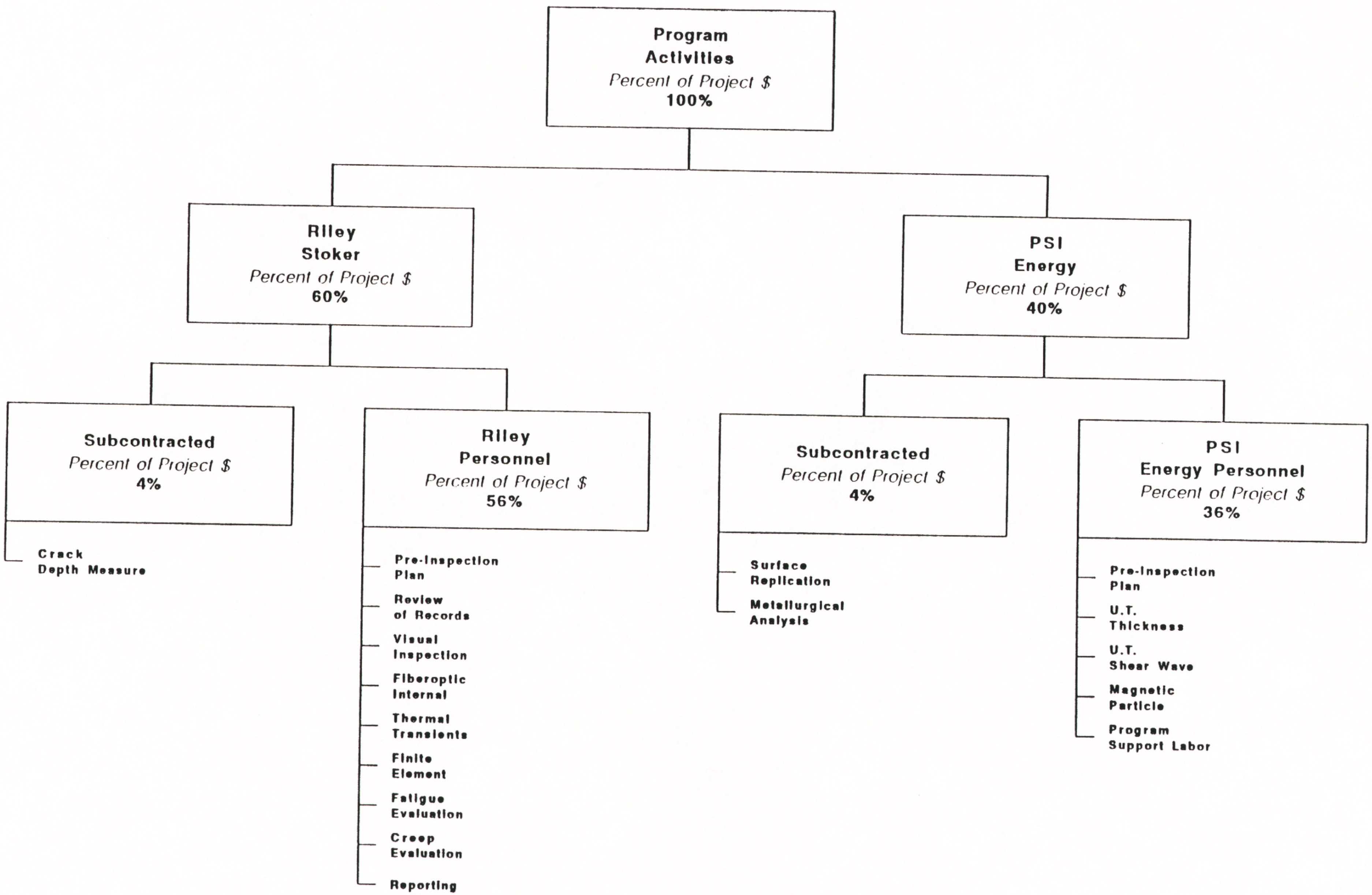


Figure 1. Wabash River Generation Station
Unit 5 Boiler

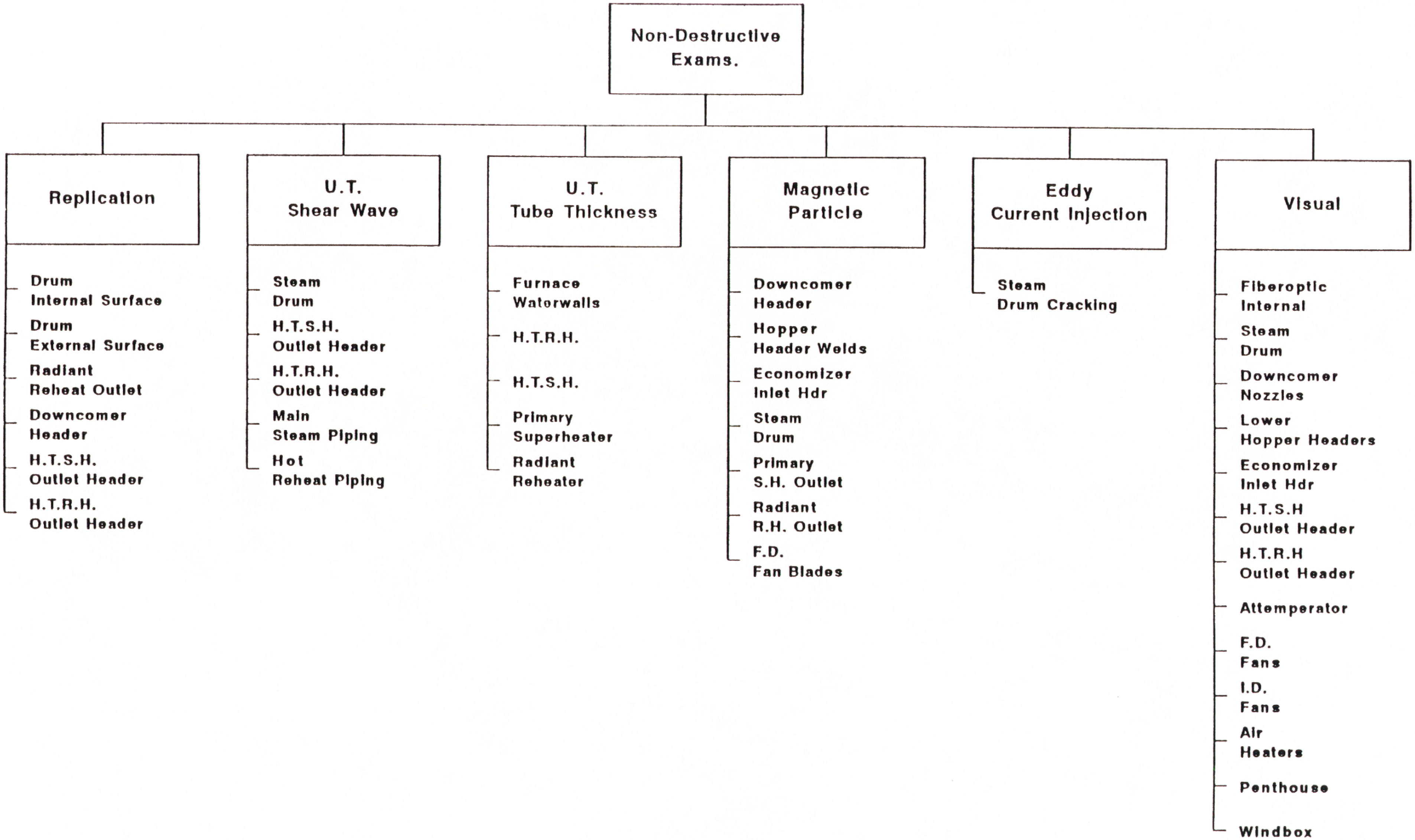
PSI Energy Wabash River Generating St.
Unit 5 Boiler Condition Assessment Prog.



Condition Assessment Responsibilities
Figure 2

PSI Energy Wabash River Generating St.

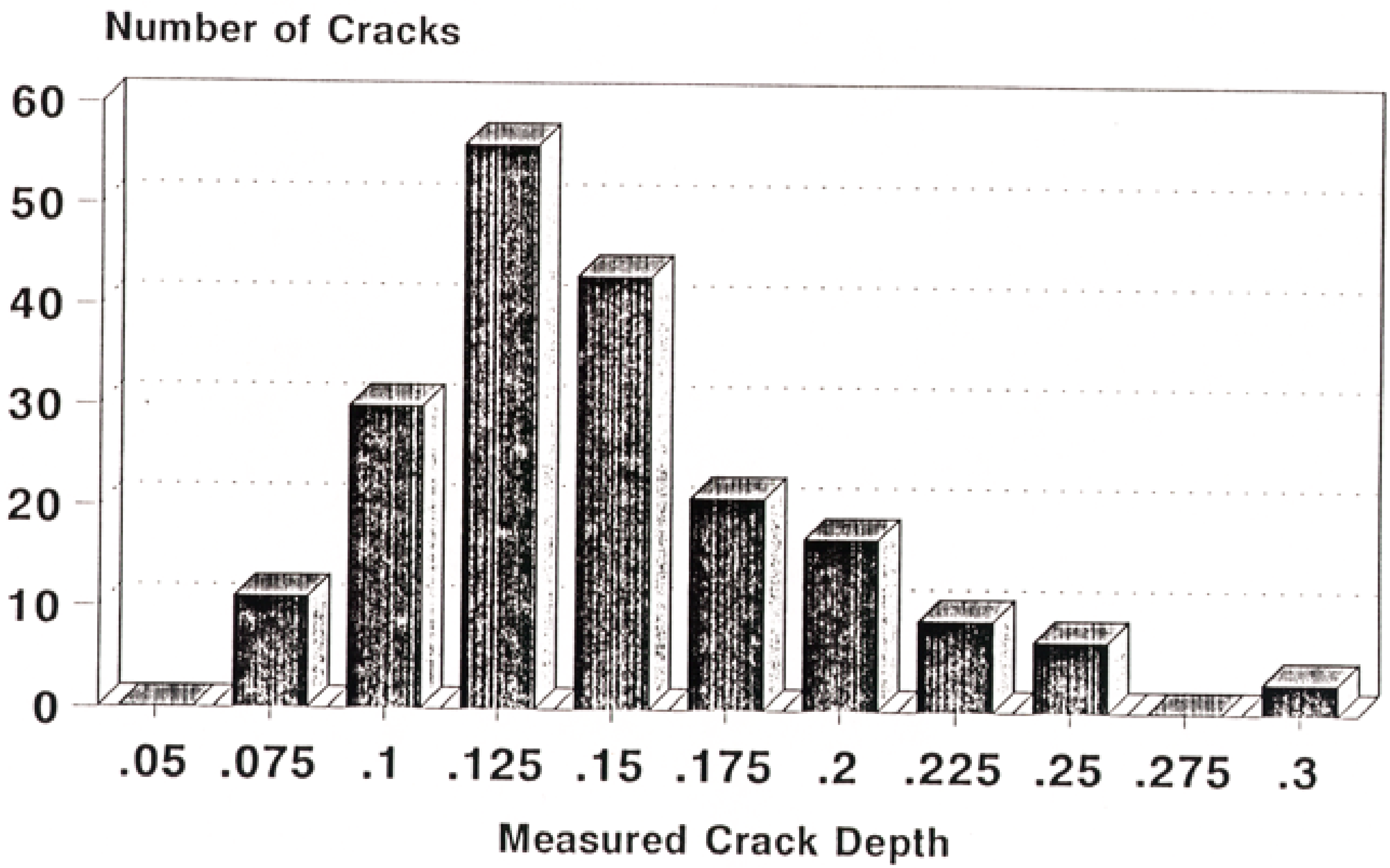
Unit 5 Boiler Condition Assessment Prog.



Inspection Activities

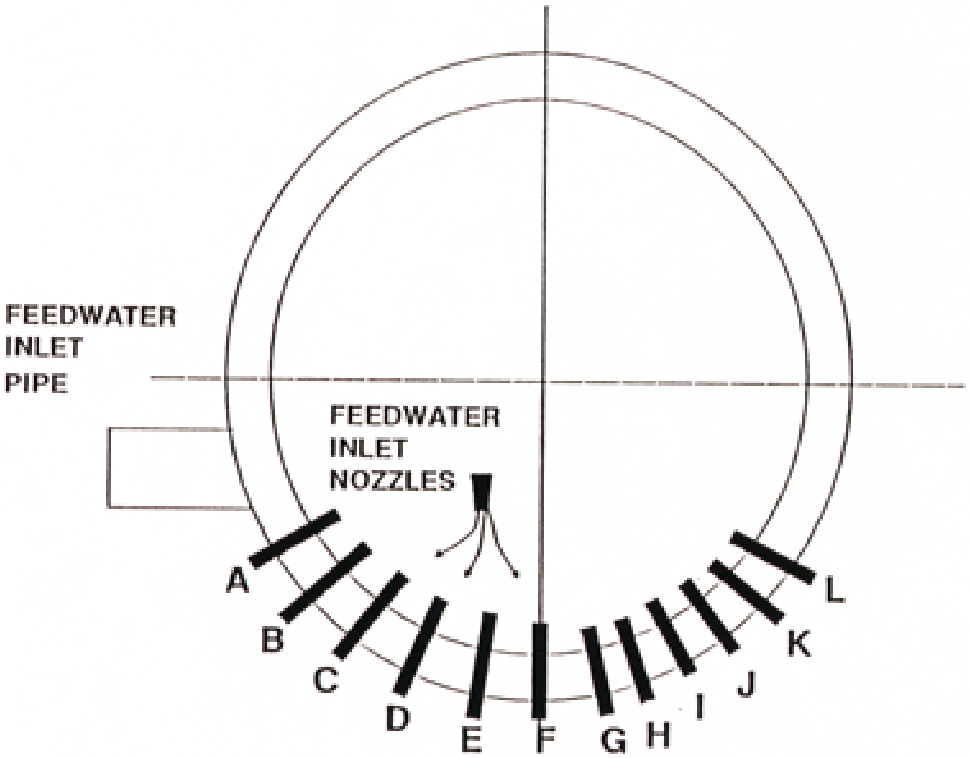
Figure 3

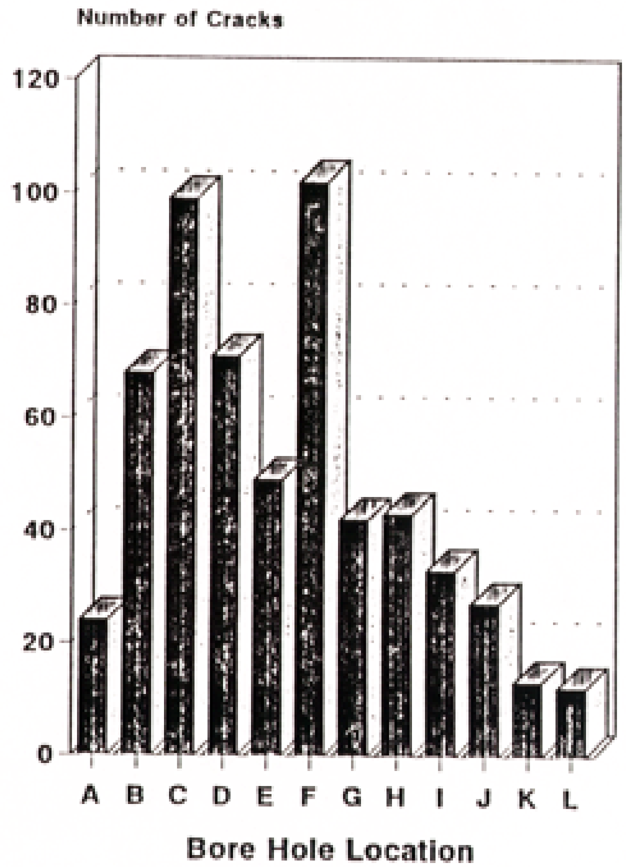
PSI Energy Wabash River Generating St.
Unit 5 Boiler Condition Assessment Prog.



Crack Depth Distribution
Figure 4

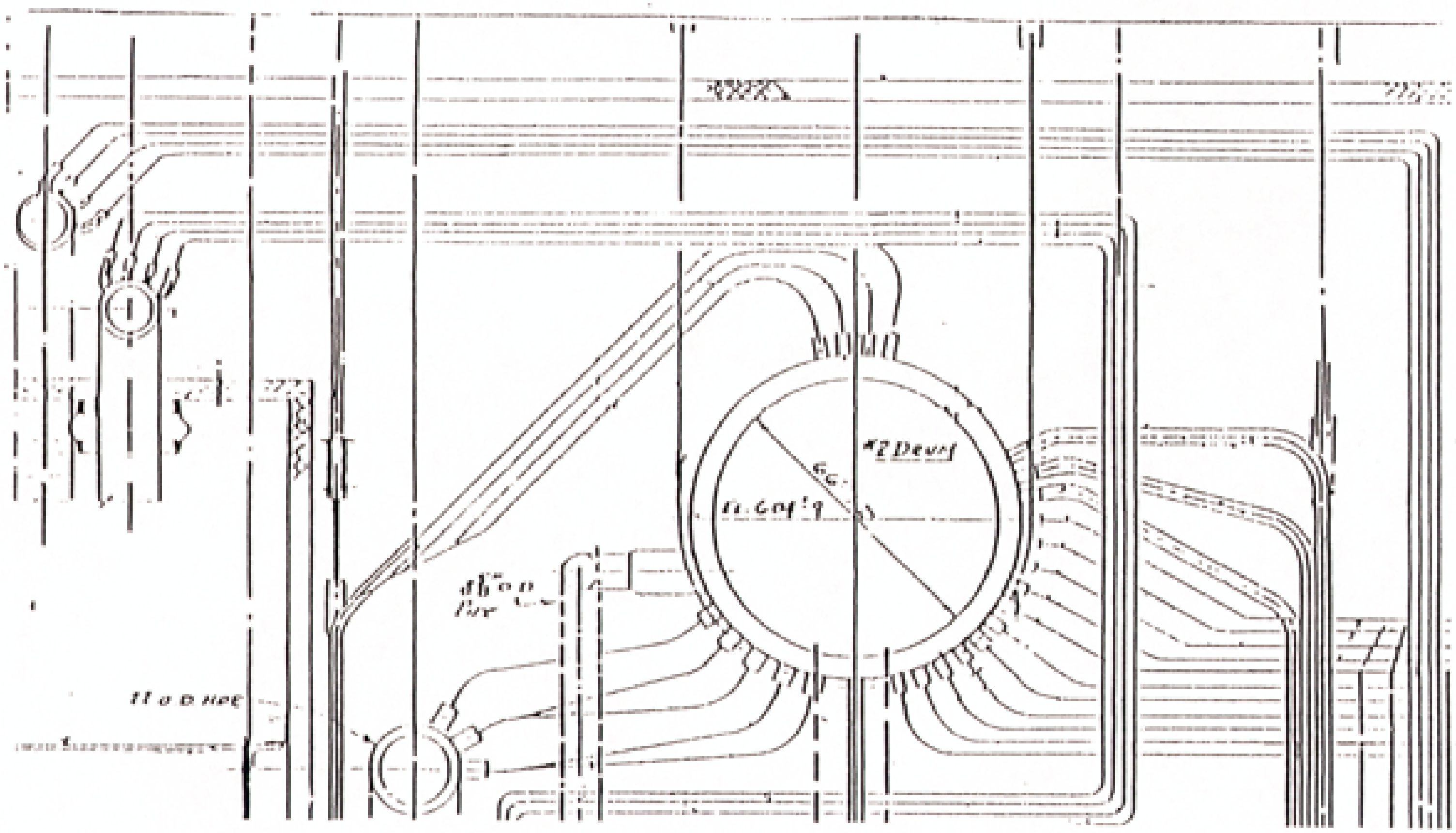
PSI Energy Wabash River Generating St.
Unit 5 Boiler Condition Assessment Prog.





Crack Location
Figure 5

PSI Energy Wabash River Generating St.
Unit 5 Boiler Condition Assessment Prog.



Steam Drum Arrangement
Figure 6