Nondestructive Evaluation: Control Rod Drive Mechanism (CRDM) Inspection Issues

2006 Update

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EPRI Project Manager

R. Barnes

ELECTRIC POWER RESEARCH INSTITUTE
3420 Hillview Avenue, Palo Alto, California 94304-1338 ▪ PO Box 10412, Palo Alto, California 94303-0813 ▪ USA
800.313.3774 ▪ 650.855.2121 ▪ askepri@epri.com ▪ www.epri.com

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This document was prepared by

Electric Power Research Institute (EPRI)
Nondestructive Evaluation (NDE) Center
1300 W.T. Harris Blvd.
Charlotte, NC 28262

Principal Investigators
R. Barnes
B. Rassler
C. Miller

KANDE International Ltd.
61 Warren Avenue
Knutsford, Cheshire WA16 0AL
United Kingdom

Principal Investigators
I. Atkinson
W. Daniels
C. Bugg

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ABSTRACT

This report summarizes ongoing activities to support examination of PWR Alloy 600/182 control rod drive mechanism (CRDM) top head penetrations. Demonstrations of equipment for inspection of CRDM tubes began in 1997. The EPRI Materials Reliability Program (MRP) took responsibility for the activity in 2001 when flaws were found in new locations. MRP discontinued funding CRDM demonstrations in 2004. EPRI Nondestructive Evaluation (NDE) Center subscriber-requested assistance (SRA) funding combined with funding from vendors was used to support demonstration activities in 2005 and 2006. MRP and EPRI NDE Center work in 2006 is focused on the development of an NDE qualification program for all reactor vessel upper head penetrations to meet the new code and regulatory requirements. Research and/or development into alternative inspection technology that could improve the efficiency and/or quality of inspection are funded by EPRI for the balance of the activities in CRDM issues.

This report describes efforts to improve inspection analysis training through lessons learned, developments addressing CRDM performance demonstration requirements in ASME Code Case 729-1, and efforts to support the MRP Inspection Issues Task Group (ITG) with determining the best approach to moving the CRDM demonstration activity into a qualification program intended to meet ASME Code requirements. Other 2006 activities included are utility inspections and vendor demonstrations of CRDMs.

ACKNOWLEDGMENTS

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CONTENTS

LIST OF FIGURES

1 INTRODUCTION

This report summarizes the results of activities to support examination of pressurized water reactor (PWR) Alloy 600/182 control rod drive mechanism (CRDM) top head penetrations. Demonstrations of the equipment for the inspection of inside surface (ID) flaws in CRDM penetrations have been ongoing since 1997. Demonstrations of equipment for inspection of the tube outside diameter (OD) flaws and weld cracking began in 2001 under the direction of the EPRI Materials Reliability Program (MRP).

Funding for 2006 was directed at development of the qualification program under the EPRI Quality Assurance Program and the continuation of supporting utilities in inspection activities and vendor demonstration under the current MRP program. This report describes the continuing efforts to improve inspection analysis capability through lessons-learned training for vendors. Efforts to support MRP with determining the best approach to changing the CRDM demonstration activity into one that meets the qualification requirements of the ASME Code are also described. A major emphasis of this project was to support utility-specific inspection issues identified by the MRP Inspection Program.

2
OBJECTIVES

The objective of this project was to continue development and support of a performance-based demonstration program to quantify the capability of nondestructive evaluation (NDE) techniques and procedures for examination of the CRDM penetration base material and the J-groove attachment weld to the reactor pressure vessel head. Conducting performance demonstrations of candidate inspection vendors under the direction of the MRP Inspection ITG will be an ongoing activity. Reporting of demonstration findings to MRP participating utilities continues on an ongoing basis. Support was provided directly to utilities conducting in-service inspections (ISIs) and pre-service inspections (PSIs). The following issues are related to these inspection activities:

- Review of inspection data due to the high cost and scheduling impact resulting from unnecessary repairs
- Unusual geometries
- Expanded inspection scopes due to requirements imposed by the U.S. Nuclear Regulatory Commission (NRC)

This project also continued developing analyst lessons-learned training. For example, sharing the results of the North Anna Unit #2 Head Penetration 54 destructive analysis, as compared to the original field inspections, will assist vendors in the determination of signal responses. This training is made available to inspection vendors on a continuing basis.

Support was provided to MRP inspections by developing the best approach for aligning the CRDM demonstration activity with ASME Section V Article 14. An approach is being reviewed to develop acceptance of some existing performance data for qualification of personnel, thereby avoiding significant cost for construction of new mockups.

A relatively new technique for performing surface examination was also investigated. Polymer replication could significantly reduce cost and exposure to personnel when performing surface examination of the attachment weld. This issue was identified at the 2004, 2005, and 2006 NDE Issues Meetings. This approach continues to be investigated for its application to identifying ID flaws in CRDMs as well as other areas that may help reduce cost and radiation exposure.

3 BACKGROUND

The CRDM demonstration process has evolved to address inspection findings and the resulting inspection requirements. An NDE demonstration program has been in place since 1997 to address cracking on the inside surface of the penetration. The demonstration process was expanded after the discovery of outside surface (OD) and attachment weld cracking. The first phase of MRP-supported demonstrations for OD-initiated flaws was assembled rapidly by the EPRI NDE Center to support fall 2001 inspections. The mockups used for the first phase of demonstrations included both field-removed penetration tube segments and a full-scale mockup containing processed electro-discharged machined (EDM) notches in the penetration tube.

The second phase of demonstrations for OD-initiated flaws began in August 2002. The mockups contained simulated primary water stress corrosion cracks (PWSCCs) in both the penetration tube and the attachment weld. The second phase of demonstrations contained a sufficient number of tube flaws to evaluate ultrasonic testing (UT) depth sizing capabilities and included a range of flaw sizes in the wetted surface of the attachment weld sufficient to evaluate eddy current detection capabilities.

This report focuses primarily on a continuation of results from the second phase of demonstration activities. The first phase of demonstrations is, however, still relevant because the information that was collected documented the capability of UT to detect actual field-removed stress corrosion flaws. It also provided support that the processed EDM notches and laboratory-grown stress corrosion cracks used in the second phase of demonstrations deliver ultrasonic responses similar to those of field-removed flaws.

4
UTILITY SUPPORT

Numerous utilities were supported during fall 2004 and spring 2005 inspections. Support was provided directly to utilities conducting both ISI and PSI activities.

Support activities are ongoing in 2006 and included three different vendor performance demonstrations in 2006. Vendors continually improved their inspection capabilities through demonstrating newly designed inspection probes, software upgrades, and probe delivery tooling. These demonstrations have been performed under strengthened security protocol to enhance the security of the truth data of the mockups.

The EPRI NDE Center staff will assist the utilities with implementing new ASME Code Case 729-1 and NRC rulemaking in 2007–2008. These documents will require greater enhancement of the demonstration program and transitioning from a demonstration to a qualification program for both procedure and personnel qualifications.

5

DEVELOPMENT IN ANALYSIS TRAINING

This project also continued the development of analysis training through lessons learned. An important aspect of producing this type of training is collecting field results and comparing them to actual destructive results from MRP's North Anna Reactor Head Project. The time-of-flight diffraction (TOFD) technique relies heavily on pattern recognition. The best way to train analysts or give them the information needed to correctly identify flaw types is to provide examples of data collected from mockups and actual inspection findings. To accomplish this, software continues to be developed that can read data from the inspection vendors' systems. A database of TOFD ultrasonic results from various flaw types as well as geometric reflectors that could be confused with flaws was developed; populating this database continues.

Utilities recognized the benefit of this database and provided access to inspection results. Inspection vendors also recognized the benefit and provided information on their ultrasonic system data file format so that their data could be analyzed by the "generic" analysis system developed under this project. KANDE International was the vendor selected by the EPRI NDE Center to provide the analysis system, called "InSight," for this effort. The database is described in Figure 5-1.

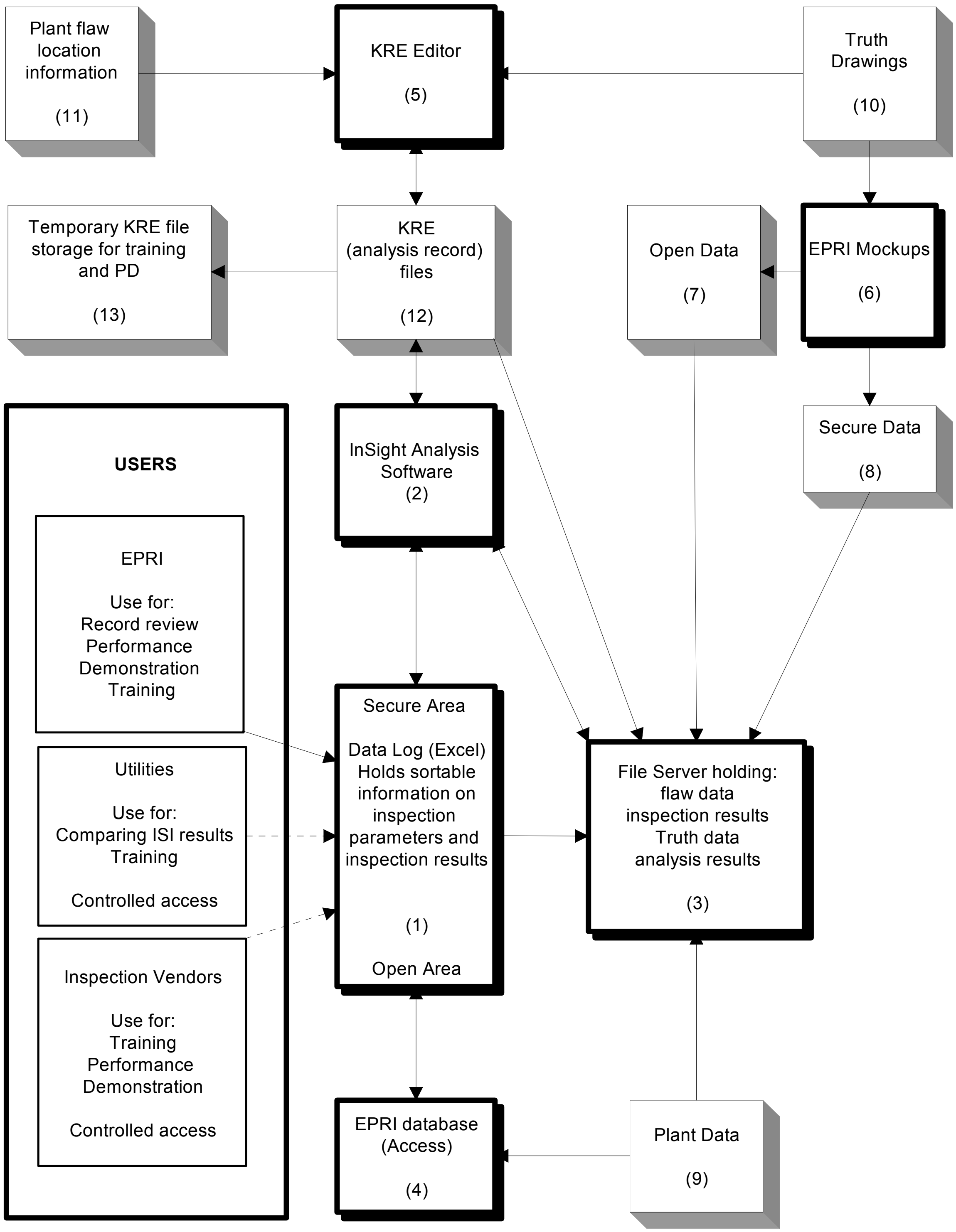

Figure 5-1
Conceptual Design for EPRI Interactive Flaw Database

Notes:

1. A log of all inspection and performance demonstration data is held by EPRI in electronic format. The location, path, and names of all data files are listed along with known details of the component, inspection setup, types of flaw present, and data quality.
2. The log is held on an Excel spreadsheet in order to be accessible to a wide range of potential users. It can be filtered and sorted using Excel's built-in tools to aid the selection of particular data parameters. When a file has been selected, InSight can be launched from the log and will open the file and any associated master record (KRE) files.
3. KANDE InSight software is a UT data analysis package, able to read and display the commonly used inspection data formats. A range of advanced signal processing tools are also available and can be used to perform additional analysis.
4. A secure server is used to hold all of the electronic data, with access controlled by EPRI.
5. The existing EPRI Access database that lists details of all plant flaws reported will be linked to the data log, enabling data from plant flaws to be accessed.
6. KRE editor is a software tool used with InSight to edit inspection records (KRE files). It is also used to synthesize flaw overlays based on known flaw positions or from test-piece manufacturing drawings.
7. Test specimens and mockups are held by EPRI and used for technique development trials and performance demonstration.
8. It contains secure data from closed test pieces and vendor performance demonstration trials can be used to verify system performance following equipment, technique, or procedural changes and for personnel qualification activities.
9. It contains data from open test pieces that can be used in operator training, technique assessment verification of system performance following equipment, and technique or procedural changes.
10. The design drawings for EPRI mockups are used to generate synthetic KRE files. These are used as training aids to assist operators in locating and identifying particular types of flaw signal or as examination tools to compare an operator's inspection results with the known flaw parameters.
11. Contains plant inspection information in the original vendor format. Particularly interesting examples of flaw responses or unusual artifacts are saved for comparison with future inspection results and for operator training purposes.

12. Information from plant inspection reports is used to generate synthetic KRE files, which can be used to direct users to the reported flaw signals. Because the data are loaded in full interactive mode, the user can interrogate the data, change the display parameters, and (if necessary) apply signal processing to optimize the analysis. This gives much greater flexibility and usefulness than is available with a written report and a selection of static images.
13. KRE files are used to store the results of an analysis performed using InSight. An existing KRE file can be recalled; and the B, C, and D scan views for each record in the file can be viewed by selecting the record. Master KRE files are used to record features of interest in the data and are stored on the server with the inspection data so that the appearance of signals generated by the features of interest can be easily recalled and displayed. Temporary or secondary KRE files generated by operators in training or undergoing performance demonstration will be stored locally. Where appropriate, these can be compared with synthetic KRE files generated from "truth" data, either as a means of self-assessment in training or as an examination tool.

6
CODIFICATION OF MRP CRDM DEMONSTRATION

Support was provided to MRP in determining the best approach for aligning the CRDM demonstration activities with the qualification requirements of the ASME Code. A gap analysis was performed to assess the various options: ASME Section V, ASME Section XI, or ASME Section XI, as implemented by PDI. An approach was also developed to use some existing data for the qualification of procedures, techniques, and personnel—thereby avoiding the significant cost of constructing new mockups. Following the gap analysis, a “roadmap” was presented at the MRP NDE Subcommittee meeting in May 2005. The performance demonstration procedure and personnel qualification process are being developed at the ERPI NDE Center.

The process for the CRDM demonstration includes the development of a project quality program to meet the requirement of regulatory requirement and in-house quality assurance program.

7 DATA GRAFTING FOR ULTRASONIC INSPECTION QUALIFICATION

Introduction

The ability to access a database of UT response data (using KANDE International's InSight software) that have been collected using vendors' inspection systems raises the possibility of using prerecorded data in inspection qualification exercises. This has advantages because, in principle, inspections could be assessed using real plant data rather than completely relying on the applicability of mockups. Extending the idea to take data from genuine flaws and mix them with response data from unflawed components holds the further benefit of significantly extending the numbers of qualification exercises, which could be constructed while the ability to conduct fully blind trials as part of the qualification exercise is maintained. This data-blending operation is also referred to as *data grafting*.

Working together, EPRI NDE Center staff and KANDE International have proposed a strategy for using prerecorded data in CRDM J-weld inspection qualifications. A portion of this strategy along with a demonstration of a prototype software system for grafting datasets was demonstrated and discussed at the MRP NDE Subcommittee meeting in Austin, Texas, in September 2005.

The main focus of the CRDM inspections is the detection and disposition of stress corrosion cracking (SCC), which tends to have a characteristic NDE appearance. It is difficult and costly to fully replicate it in mockups. In particular, for ultrasonic inspections that rely heavily on analysts' pattern recognition skills, there is the concern that analysts trained and tested exclusively on responses from mockups might fail to recognize responses from genuine SCC. Although this is potentially the case for any inspection, this issue is a more pressing concern here because fabrication of realistic defects in the CRDM geometry is more difficult and costly than it is for many other inspection situations.

An additional issue is that there are a number of fabrication and repair imperfections found in the plant that give responses that can be confused with SCC. Analysts must be able to distinguish these imperfections from SCC.

Proposed Qualification Strategy for SCC

From information collected on SCC flaws in plants and studies of lab-grown SCC, it is apparent that SCC flaws in the tubing material have a characteristic appearance that is different in some respects than that observed in conventional synthetic flaws used in qualification. Although some of these features could be reproduced in mockups, it would be very costly. The strategy proposed here for the use of prerecorded data is outlined below:

1. Improved access to SCC response data from field-removed and lab-grown samples for training purposes, which enables analysts to be familiar with typical response data
2. Use of a combination of response data from genuine plant flaw and lab-grown SCC to obtain the necessary confidence that analysts can recognize and discriminate between actual crack responses and responses from non-relevant reflectors

Step 2 will be delivered by using field data and supplementing it with data from lab-grown SCC. In the scheme proposed, data to be analyzed in qualification will have been originally collected by the vendor undergoing qualification using the methods and, as far as possible, the equipment that will be deployed in the field. The degree to which field samples may be used, therefore, depends on how many flaws the candidate vendor has found in the field. As a result, for established vendors, there may be sufficient data; for vendors new to this inspection, there may be no directly relevant samples. In this case, there will be a higher reliance on data from lab-grown flaws.

Use of Lab-Grown SCC Specimens

It is envisioned that SCC flaws will be grown in specimens of the type shown in Figure 7-1. OD cases would also be grown. Note that the specimens are only sections of the full length and circumference of the plant items and that they are manufactured from typical Inconel 600 tubing backed by Inconel 182 weld metal.

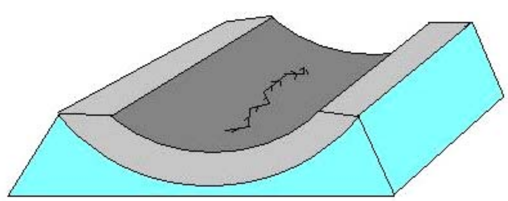

Figure 7-1
Lab Grown SCC Sample: ID Case

The vendor would collect data from the specimens using its own inspection methods and equipment. Data would be retained by EPRI.

EPRI already has significant amounts of data from vendors' inspection systems deployed both on mockups and in the field. These data are stored in the vendors' own file formats in computer files. EPRI already possesses the capability to read these data formats. A prototype data-blending tool has been developed and demonstrated.

Lab-grown specimens, which are relatively inexpensive, can then be destructively examined and the true nature and extent of the flaws ascertained—beyond dispute. In this way, analysts will be able to analyze real SCC response data in realistic configurations. The nature and extent of the SCC will be known accurately to EPRI following the specimens' destructive examination. While there is likely to be a requirement for the vendor to collect additional data from the lab-grown SCC, the vendor need not scan the full inspection volume—and so the collection activity need not be excessively time consuming. A combination of using field data and data from specimens strengthens confidence in the appropriateness of the outcome.

Grafting Software

A special development of KANDE International's InSight software has been produced and demonstrated. The software allows the user to open a donor data file and isolate a volume of interest that contains a flaw's echo response. This selected volume can then be inserted into either the same or a different file. The recipient file can then be saved in the original file format, which can then be analyzed by the inspection vendor using its own analysis software.

Use of the demonstration software, in most situations in which it has been tested, confirms that the method is appropriate and produces a convincing dataset when used with care. There are currently some restrictions on how the grafting software could be used, and a number of software enhancements are required in order to eliminate these restrictions and improve some aspects of the grafting operation.

While the grafting method has specifically been demonstrated for the TOFD inspection of CRDM tubing, it has a far wider field of potential use with other inspection qualifications.

8
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