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Abstract

The U.S. Department of Energy (DOE), in cooperation with the Electric Power Research Institute (EPRI) and U.S. nuclear power plant utilities, is preparing a series of aging management guidelines (AMGs) for commodity types of components (*e.g.*, heat exchangers, electrical cable and terminations, pumps). Commodities are included in this series based on their importance to continued nuclear plant operation and license renewal. The AMGs contain a detailed summary of operating history, stressors, aging mechanisms, and various types of maintenance and surveillance practices that can be combined to create an effective aging management program. Each AMG is intended for use by the systems engineers and plant maintenance staff (*i.e.*, an AMG is intended to be a "hands-on" technical document rather than a licensing document). The heat exchangers AMG, published in June 1994, includes the following information of interest to nondestructive examination (NDE) personnel:

- Aging mechanisms determined to be non-significant for all applications,
- Aging mechanisms determined to be significant for some applications,
- Effective "conventional" programs for managing aging, and
- Effective "unconventional" programs for managing aging.

Since the AMG on heat exchangers was published four years ago, a brief review has been conducted to identify emerging regulatory issues, if any. The results of this review and "lessons learned" from the collective set of AMGs are presented.

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Introduction

License Renewal

Nuclear power plants applying for an amended (extended) operating license under the provisions of the License Renewal Rule[1] must demonstrate that age-related degradation of systems, structures, and components (SSCs) will be managed and that all SSCs will continue to perform their safety function(s). Therefore, plant operators must identify and perform activities necessary to manage SSC aging and ensure continued performance of safety function(s).

The U.S. Department of Energy (DOE)-sponsored Commercial Light Water Reactor (CLWR) Program,[a] in cooperation with the Electric Power Research Institute (EPRI) Life Cycle Management (LCM) Subcommittee, is working to resolve technical issues that may be barriers to continued plant operation. The focus of the CLWR and LCM programs is on long-term issues that may limit operation during a license renewal term.

As part of this coordinated program, DOE sponsored, through Sandia National Laboratories, the preparation of a series of aging management guidelines (AMGs) for commodity-type comoponents. AMGs are written for systems engineers and the maintenance staff. They are intended to work as a tool to support continued operation of nuclear power plants during the term of the original operating license, and for periods that extend beyond the original 40-year license period.

The AMGs are a continuation of a DOE-EPRI joint effort to develop license renewal industry reports (IRs), which evaluate aging concerns in critical systems, structures, and components (SSCs), such as reactor pressure vessels, reactor coolant pressure boundary piping, containment structures, and low-voltage, environmentally-qualified cables. The IR effort, which was coordinated with the Nuclear Management and Resources Council (NUMARC),[b] produced ten reports that were submitted to the U.S. Nuclear Regulatory Commission (NRC).

The collective body of technical and licensing reports [AMGs, IRs, and technical reports prepared by individual utilities and by owner's groups through generic license renewal programs (GLRPs)] is expected to address aging management issues for nuclear power plants. With the submittal of the first license renewal application,[c] a formal means of identifying NRC questions and achieving regulatory closure on technical issues is now available.

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[a] The predecessor of the DOE Commercial Light Water Reactor (CLWR) program was the Plant Lifetime Improvement (PLIM) Program

[b] The Nuclear Management and Resources Council (NUMARC) is now part of the Nuclear Energy Institute (NEI).

[c] The first license renewal application was submitted to the NRC on April 10, 1998, by the Baltimore Gas & Electric Company, for the Calvert Cliffs Nuclear Power Plant.

The AMGs cover the following commodities. The numbers in parenthesis identify the Sandia report containing the guidelines.

- Batteries, stationary (safety-related dc power system) [SAND93-7071],
- Battery chargers, inverters, uninterruptible power supplies [SAND93-7046],
- Cable and terminations, electrical [SAND96-0344],
- Containment penetrations {in progress},
- Heat exchangers [SAND93-7070],
- Motor control centers [SAND93-7069],
- Piping and tubing, non-reactor coolant pressure boundary (Non-RCPB) {in progress},
- Pumps [SAND93-7045],
- Switchgear, electrical [SAND93-7027],
- Tanks and pools [SAND96-0343], and
- Transformers, power and distribution [SAND93-7068].

Similar Reports

In addition to the heat exchangers AMG, the following similar reports have been published:

- Babcock & Wilcox Owners Group, Generic License Renewal Program Report BAW-2270, "Non-Class 1 Mechanical Implementation Guideline and Mechanical Tools," Appendix G, "Heat Exchangers," Revision 1, November 1996.
- Westinghouse LCM/LR Program Report WCAP 14341, "Generic Technical Report on Aging Management Evaluation for Heat Exchangers," Revision 1, May 1997
- NRC Nuclear Plant Aging Research (NPAR) Program Report NUREG/CR-5779, "Aging of Non-Power-Cycle Heat Exchangers Used in Nuclear Power Plants," July 1992

Balance of Plant Heat Exchanger Nondestuctive Examination

The EPRI Balance of Plant (BOP) Heat Exhanger Nondestructive Examination (NDE) symposium requested additional information on overall aging management programs for nuclear power plant heat exchangers. This paper summarizes both the AMG methodology and specific information from the heat exchangers AMG. From an NDE perspective, note that the heat exchangers AMG does not include a detailed description of NDE techniques, nor does it explain the basis for NDE. It does describe aging mechanisms of interest, in rank order. In addition, it explains which programs, including NDE techniques, are currently viewed as effective tools for managing aging and identifies opportunities for future improvements.

The AMG viewpoint that NDE personnel may wish to consider is the integrated aging management program. Given a summary of significant aging mechanisms and design and operational considerations, NDE personnel can develop/enhance NDE systems. Improvements in the methods of locating and characterizing aging, and generating outputs that seamlessly interface with design and operational evaluations of aged components, are needed. New and/or enhanced NDE systems tailored to satisfy the constraints identified in the heat exchangers AMG are most likely to be useful to utilities seeking to improve their aging management and maintenance programs.

The material that follows is organized as a guide to using the heat exchangers AMG. The section, table, and figure numbers refer to the numbers in the heat exchangers AMG. Each section begins with a discussion of the AMG methodology, followed by specific information from the heat exchangers AMG.

The Heat Exchangers AMG

Section 2, "Introduction"

The scope of SSCs covered by the license renewal rule is defined in 10 CFR 54.4:

(a) Plant systems, structures, and components within the scope of this part are--

   (1) Safety-related systems, structures, and components which are those relied upon to remain functional during and following design-basis events (as defined in 10 CFR 50.49 (b)(1)) to ensure the following functions--

      (i) The integrity of the reactor coolant pressure boundary;

      (ii) The capability to shut down the reactor and maintain it in a safe shutdown condition; or

      (iii) The capability to prevent or mitigate the consequences of accidents that could result in potential offsite exposure comparable to the guidelines in 10 CFR 50.34(a)(1) or 100.11 of this chapter, as applicable.

(2) All nonsafety-related systems, structures, and components whose failure could prevent satisfactory accomplishment of any of the functions identified in paragraphs (a)(1) (i), (ii), or (iii) of this section.

(b) All systems, structures, and components relied on in safety analyses or plant evaluations to perform a function that demonstrates compliance with the Commission's regulations are included in the scope, including:

(1) Fire protection (10 CFR 50.48[2]),

(2) Environmental qualification (10 CFR 50.49[3]),

(3) Pressurized thermal shock (10 CFR 50.61[4]),

(4) Anticipated transients without scram (10 CFR 50.62[5]), and

(5) Station blackout (10 CFR 50.63[6]).

The following heat exchangers are included in the Heat Exchangers AMG:

Table 2-1. Heat Exchangers in Scope of AMG

Heat Exchangers Located in BWR Plants	Heat Exchangers Located in PWR Plants
Component Cooling Water Heat Exchangers (Note 1)	Chemical and Volume Control Excess Letdown Heat Exchangers
Drywell Coolers	Chemical and Volume Control Letdown Heat Exchangers
Emergency Core Cooling System Room Coolers	Chemical and Volume Control Regenerative Heat Exchangers
Emergency Diesel Generator Jacket Water Coolers	Chemical and Volume Control Seal Water Heat Exchangers
Emergency Diesel Generator Lubrication Oil Coolers	Component Cooling Water Heat Exchangers (Note 1)
High Pressure Coolant Injection Gland Seal Condensers	Emergency Core Cooling System Room Coolers
High Pressure Coolant Injection Lubrication Oil Coolers	Emergency Diesel Generator Jacket Water Coolers
Miscellaneous Oil Coolers	Emergency Diesel Generator Lubrication Oil Coolers
Reactor Core Isolation Cooling Lubrication Oil Coolers	Miscellaneous Oil Coolers
Reactor Water Cleanup Non-Regenerative Heat Exchangers	Residual Heat Removal Heat Exchangers (Note 3)
Reactor Water Cleanup Regenerative Heat Exchangers	Spent Fuel Pool Cooling Heat Exchangers
Residual Heat Removal Heat Exchangers (Note 2)	
Spent Fuel Pool Cooling Heat Exchangers	

Notes:

1. Includes various system names, such as component cooling water, emergency equipment cooling water, essential equipment cooling water, reactor building closed cooling water and essential service water

2. Includes various system names, such as decay heat removal, low pressure coolant injection, shutdown cooling, and containment cooling.

3. Includes various system names, safety injection, shutdown cooling, and decay heat removal.

Section 3, "Equipment/Components Evaluated: Scope"

An extensive literature search is performed before the preparation of an AMG. Typical sources include:

- EPRI reports,
- EPRI Nuclear Maintenance Applications Center (NMAC) maintenance guides,
- NRC bulletins, information notices, circulars, generic letters,
- NRC NPAR reports, NUREGs,
- Code of Federal Regulations (CFR),
- Manufacturer's manuals
- Standards - American National Standards Institute (ANSI), American Society for Testing and Materials (ASTM), American Society of Mechanical Engineers (ASME), Institute of Electrical and Electronics Engineers (IEEE), etc.
- International references and technical papers

Operating history data are gathered from the following sources:

- INPO nuclear plant reliability data system (NPRDS) database,
- NRC licensee event report (LER) database,
- Host[d] utilities,
- Individual plant surveys, and
- NRC bulletins, information notices, etc.

Data Sources for Heat Exchangers

NPRDS Data. About 24% of reported heat exchanger failures were considered age-related; the remaining failures were attributed to other causes such as design and maintenance. The most common subcomponents to fail from age-related degradation were tubes (61%) and shells (9%). The most significant aging mechanisms were fouling

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[d] Host utilities are utilities that agree to support the AMG preparation effort in a more substantial manner than providing general review and comments. Typically, a host utility provides INPO NPRDS access, assigns personnel to gather plant-specific insights and information, and performs in-depth technical reviews supported by plant-specific examples. This approach is used to ensure that the AMG covers theoretical, design, and actual performance issues.

(31%) and corrosion (17%). Heat exchangers experiencing the greatest number of failures in boiling water reactors (BWRs) were in the residual heat removal system (44%), followed by reactor building closed cooling water (32%) and emergency diesel generator cooling water systems (17.7%). Heat exchangers with the most failures in pressurized water reactors (PWRs) were in the component cooling water system (55%), followed by containment cooling systems (14%) and the emergency diesel generator cooling water system (10%).

LER Data. About 42% of reported heat exchanger failures were considered age-related. The most significant aging mechanisms were fouling (44%), followed by erosion/corrosion (25%). Heat exchangers with the most failures in BWRs were in the residual heat removal (31%) and emergency diesel generator cooling water (14%) systems. Heat exchangers with the most failures in PWRs were the containment fan unit coolers (35%) and component cooling water systems (18%).

NRC Generic Communications. NRC generic communications were reviewed to identify potential regulatory issues. Generic communications related to heat exchangers are listed for both aging and other issues (*e.g.*, design, construction, operation).

Table 3-13. List of NRC Information Notices, Bulletins, Circulars, and Generic Letters Related to Heat Exchanger Degradation

	INFORMATION NOTICES
IN 81-21	Potential Loss of Direct Access to Ultimate Heat Sink
IN 83-56	Operability of Required Auxiliary Equipment
IN 84-71	Graphitic Corrosion of Cast Iron in Salt Water
IN 85-24	Failures of Protective Coatings in Pipes and Heat Exchangers
IN 85-30	Microbiologically Induced Corrosion of Containment Service Water System
IN 85-33	Undersized Nozzle-to-Shell Welded Joints in Tanks and Heat Exchangers Constructed Under the Rules of the ASME Boiler and Pressure Vessel Code
IN 85-56	Inadequate Environment Control for Components and Systems in Extended Storage or Lay-Up
IN 86-96	Heat Exchanger Fouling Can Cause Inadequate Operability of Service Water Systems
IN 88-37	Flow Blockage of Cooling Water to Safety System Components
IN 90-26	Inadequate Flow of Essential Service Water to Room Coolers and Heat Exchangers for Engineered Safety-Feature Systems
IN 90-80	Sand Intrusion Resulting in Two Diesel Generators Becoming Inoperable

IE BULLETINS	
BL 80-24	Prevention of Damage Due to Water Leakage Inside Containment
BL 81-03	Flow Blockage of Cooling Water to Safety System Components by Corbicula SP. (Asiatic Clam) and Mytilus SP. (Mussel)
	IE CIRCULARS
C 80-07	Problems With HPCI Turbine Oil System
	GENERIC LETTERS
GL 89-13	Service Water System Problems Affecting Safety-Related Equipment

Section 4, "Stressors and Aging Mechanisms"

Standard aging *terminology*, per EPRI Report TR-100844,[7] is used in all AMGs. In addition, the significance of aging mechanisms is presented using "if-then" criteria (*e.g.*, if the operating temperature is less than ___°C [___°F], then _______ _______ is not a concern).

A two-part evaluation is performed to define the applicable aging mechanisms.

First, the effect(s) of each stressor (*e.g.*, temperature, humidity, voltage, operating cycles, and radiation) on SSC operation are determined. This effort leads to the identification of aging mechanisms associated with stressors that cause degradation.

Second, industrywide operating experience is examined, with emphasis on NRC LERs, information notices, bulletins, and circulars, and INPO NPRDS data. NRC information notices, bulletins, and circulars are reviewed to identify age-related failures and the associated aging mechanism(s). Events described in NPRDS and LERs are evaluated in a similar manner; in addition, the numbers of particular types of failures are reviewed to begin developing aging statistics. A review of industrywide operating experience (Section 3) provides a descriptive characterization of SSC aging using actual plant and vendor data to substantiate and refine those aging mechanisms postulated to occur as a result of stressors.

Following the effort to catalog aging mechanisms, the significance of each mechanism is determined. When sufficient time has elapsed for an aging mechanism to be recognizable and aging has not been observed, it is designated "non-significant." Aging mechanisms that are (1) confirmed by operating or overhaul experience, (2) exhibit a high probability of occurrence, (3) could result in a significant failure, or (4) may become significant in the future, are designated "significant."

Not all forms of tube degradation are significant aging mechanisms. The following forms of tube degradation are reviewed in the AMG:

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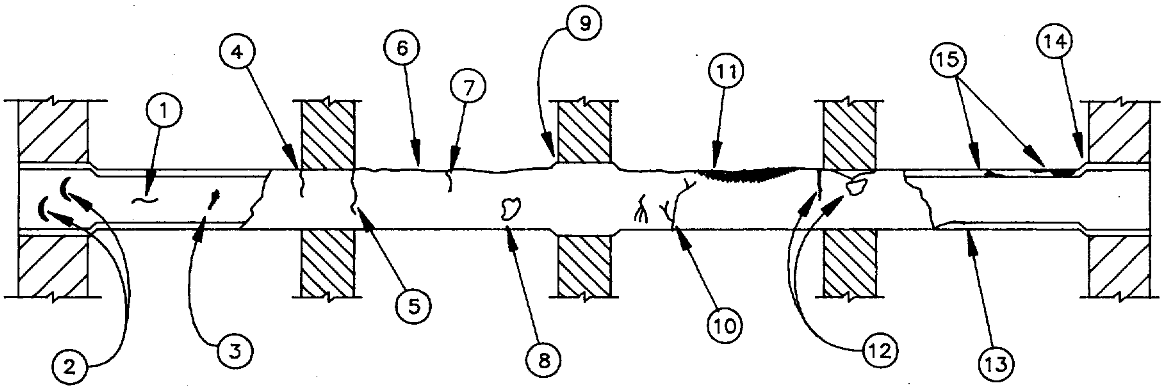

1. Inlet erosion and uniform wastage
2. Cavitation and erosion pitting
3. Debris or "clamshell" pits
4. Support wear
5. Fatigue cracks
6. Tube-to-tube wear
7. Midspan fatigue cracks
8. Dealloying
9. Overrolling or freeze bulges
10. Stress corrosion cracking
11. Steam erosion
12. Corrosion at supports
13. Deposit-type pitting and electromechanical corrosion filling
14. Overrolling at tubesheet
15. Manufacturing defects

Figure 4-3. Common Heat Exchanger Tube Degradation.

Heat exchanger aging mechanisms determined to be non-significant are:

- Thermal embrittlement (Section 4.3.1.1),
- Creep (Section 4.3.1.1),
- Thermal fatigue (Section 4.3.1.3),
- Irradiation assisted stress corrosion cracking (Section 4.3.1.2), and
- Neutron embrittlement (Section 4.3.1.2).

Heat exchanger aging mechanisms determined to be significant, for some applications, are:

- Stress relaxation (Section 4.3.1.1),

- Mechanical fatigue (Section 4.3.1.4),
- Corrosion (Section 4.3.1.5),
- Stress corrosion cracking (Section 4.3.1.6),
- Erosion and erosion/corrosion (Section 4.3.1.7),
- Wear (Section 4.3.1.8), and
- Fouling (Section 4.3.1.9).

Section 5, "Effective Management of Aging Mechanisms"

Section 5 of the AMG discusses techniques for managing the aging mechanisms that are determined to be significant in Section 4. "Conventional" approaches to management of aging mechanisms are industrywide maintenance, inspection, testing, and surveillance techniques or programs. "Unconventional" approaches, those used by other industries or a small number of nuclear power plants, are also included. The effectiveness of both conventional and unconventional techniques and/or programs is evaluated in terms of their ability to manage potentially significant aging mechanisms.

Within the context of license renewal, age-related degradation must be addressed by an effective program, or be shown not to require an effective program. An effective program is a documented program to manage age-related degradation that ensures that a SSC will continue to perform its safety function(s), or will not prevent the performance of a safety function. Effective programs must:

1. Ensure identification and mitigation of age-related degradation,
2. Contain acceptance criteria against which the need for corrective action can be evaluated, and ensure that timely corrective action will be taken when these acceptance criteria are not met, and
3. Be documented and implemented by facility operating procedure(s) and reviewed by the onsite review committee.

The effectiveness of plant procedures in detecting and mitigating degradation is demonstrated by:

1. Showing that established programs and procedures effectively ensure the capability of the components being evaluated to perform their safety function(s) throughout their entire service life, or

2. Enhancing program and/or procedures to manage aging mechanism(s) that may not be adequately addressed by existing programs and/or procedures.

Description of Heat Exchanger Aging Management Programs

Conventional Programs. Conventional aging management programs for heat exchangers include ASME Section XI Inservice Inspection, the 1987 edition of ASME Code for Operation and Maintenance of Nuclear Power Plants (OM Code),[8] Parts 2, 11, and 21,[e] preventive maintenance (periodic, predictive, planned) and microbiologically influenced corrosion (MIC) control.

Unconventional Programs. Unconventional aging management programs applied to heat exchangers include controlled layup when drained, operator activities, coating surveys, operating/industry experience reviews, spare parts shelf life, and receipt inspection. Effective programs presented in the AMG (*e.g.*, visual inspection, leak testing, eddy current examination of tubing, and vibration monitoring) are often specified by heat exchanger manufacturers.

Effectiveness. NPRDS data suggest that failure rates for heat exchangers have been increasing slightly in recent years. This may be because the ASME OM Code is not yet required. If ASME OM Code requirements are implemented in the aging management program, evaluation results suggest that the industry could effectively detect and/or mitigate heat exchanger aging.

Additional Plant-Specific Considerations. The ASME OM Code, Parts 2, 11, and 21 have not been endorsed by the ASME Boiler and Pressure Vessel Committee, nor have they been incorporated in the Code of Federal Regulations (10 CFR 50.55a[9]) as mandatory testing and inspection requirements. However, elements of the OM Code include provisions to effectively detect and/or mitigate aging and degradation occurring in heat exchangers. Since these parts of the OM Code are not mandatory, nuclear utilities may not be following the concepts defined in Parts 2, 11, and 21. If this is the case, utilities may find it beneficial to review these unendorsed parts and upgrade or enhance their preventive maintenance program to include elements of the OM Code.

Differences Between NPAR and AMG Results

The heat exchanger AMG did not evaluate heat exchanger gasket failures because gaskets are periodically replaced and replaceable subcomponents are not included in the scope of a license renewal review. Plant maintenance procedures effectively

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[e] The 1990 Edition of the ASME Operations and Maintenance Code does not include a section equivalent to the 1987 Edition, Parts 2, 11, and 21. Part 2 is included in ASME-S/G-1990, "Standards and Guides for Operation and Maintenance of Nuclear Power Plants."

manage replaceable items like gaskets. Gasket failures are discussed in the NPAR Report (NUREG/CR-5779).

In general, the stressor and aging mechanism evaluations presented in AMGs compare favorably with NPAR reports. The effectiveness of maintenance programs and aging management practices are not included in the scope of NPAR results; therefore, industry/NRC concurrence on what may constitute effective aging management could not be assessed. The criteria for effective aging management in each AMG are consistent with the criteria in the License Renewal Rule and the Maintenance Rule.

Conclusions

General Conclusions – Collective Lessons Learned

The AMGs show that:

- Existing knowledge is sufficient to identify and describe applicable aging mechanisms,
- No new aging mechanisms were discovered,
- Comparisons of aging mechanism evaluations in AMGs and NPAR reports were favorable,
- Qualitatively, NPRDS and LER data show similar results, but not quantitatively,
- In most cases, existing programs effectively manage aging,
- In a few cases, maintenance and/or surveillance program upgrades may be desirable, and
- Existing data from NPRDS or LER databases are neither sufficiently complete nor accurate to support statistical analysis.

While individual utilities and owner's groups are expending considerable resources on similar technical evaluations of commodities, further industrywide efforts are recommended:

- NPRDS does not facilitate a structured evaluation of the data. While this may be improved in the electronic plant experience (EPEX) database, the data in the NPRDS (and LER) databases are not input in a manner that facilitates calculation of mean-time-between-failure (MTBF), or other statistical parameters. While the words "root cause evaluation" appear in NPRDS, the actual root cause was usually determined by working back through utility maintenance records corresponding to the database record. From a database perspective, routine use of "miscellaneous" and "unknown" is a major roadblock to effective data analysis. It's also general practice to avoid reporting what might be called nonactive failures (*e.g.*, problems detected by surveillance) since a "failure did not occur." If the industry wants NPRDS and EPEX to evolve into something more than a loose collection of references to plant experience, improved guidelines and more resources are needed. Utilities will have to determine whether the future benefits are worth the additional investment.

- AMGs are becoming dated and there are no plans to maintain these documents. With the rapid evolution of NDE techniques, improved Maintenance Rule implementation strategies, etc., periodic updates of the AMGs would be beneficial. Utilities potentially interested in initiating efforts to periodically update the AMGs should contact the DOE CLWR program director or the EPRI LCM project manager.

- Specific to the heat exchangers AMG, the report could be updated to regroup the evaluations. The existing grouping treats each type of heat exchanger independently and there is a great deal of repetition in the document. Subsequent AMGs used a streamlined evaluation flowchart approach (*e.g.*, the tanks and pools AMG).

Owner's Group and Utility Experience with AMGs

The program coordinator of the B&W Generic License Renewal Program stated, "Having participated in the development of two of these reports [AMGs], we find them to be very useful." The vice chairman of the Westinghouse Owners Group Life Cycle Management License Renewal Working Group stated, "We view these guidelines [AMGs] as an effective and beneficial use of DOE [Department of Energy] funds and support the development of additional AMGs for the industry."

In addition to the owner's groups, individual utility personnel are using AMGs. Commonwealth Edison Company, Duke Power Company, and GPU Nuclear have stated that AMGs are solid technical documents that can be used to support maintenance, life cycle management, and license renewal activities.

An electronic version of most AMGs is available from Sandia National Laboratories. In some cases, the electronic version includes spreadsheets and other tools that can be applied to plant-specific problems. For example, Duquesne Light Company used the spreadsheets from the electrical cable and terminations AMG to evaluate cable aging in a conduit raceway protected by Thermo-Lag®.

Heat Exchanger Developments Since 1994

Based on an April 1998 review of NRC generic communications including bulletins, information notices and generic letters, there have been no regulatory developments since the literature search for the Heat Exchangers AMG was performed. The conclusions in the reports listed here in the "Similar Reports" section (above) are similar to those in the heat exchangers AMG. The main differences between the reports are document organization and additional information on improved NDE for heat exchanger tubing.

Recommendations

1. Perceived heat exchanger NDE challenges are identified throughout Section 5 of the heat exchangers AMG. Projects to resolve these issues should be communicated throughout the industry.

2. Operations and maintenance codes need to be updated periodically to reflect rapidly expanding NDE capabilities.

3. Codes and their basis documents contain a wealth of knowledge that should be incorporated in industry documents like the heat exchangers AMG.

References

1. Title 10, Code of Federal Regulations, 10 CFR Part 54, "Requirements for the Renewal of Operating Licenses for Nuclear Power Plants," May 8, 1995.

2. Title 10, Code of Federal Regulations, 10 CFR Part 50.48, "Fire Protection," May 27, 1988.

3. Title 10, Code of Federal Regulations, 10 CFR Part 50.49, "Environmental Qualification of Electrical Equipment Important to Safety for Nuclear Power Plants," May 27, 1988.

4. Title 10, Code of Federal Regulations, 10 CFR Part 50.61, "Fracture Toughness Requirements for Protection Against Pressurized Thermal Shock Requirements," May 15, 1991.

5. Title 10, Code of Federal Regulations, 10 CFR Part 50.62, "Requirements for Reduction of Risk from Anticipated Transients without Scram (ATWS) Events for Light-Water-Cooled Nuclear power plants," April 3, 1989.

6. Title 10, Code of Federal Regulations, 10 CFR Part 50.63, "Loss of All Alternating Current Power," June 1, 1988.

7. EPRI Report TR-100844, "Nuclear Power Plant Common Aging Terminology," Electric Power Research Institute, November 1992.

8. ASME/ANSI OM-1987, "Operation and Maintenance of Nuclear Power Plants" and associated addenda, 1987.

9. Title 10, Code of Federal Regulations, 10 CFR Part 50.55a, "Conditions of Construction Permits, Codes and Standards," March 25, 1994.