Development of a Database for Polymer Applications

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EPRI Project Manager

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ABSTRACT

This technical update report describes the structure and potential uses of a database that is under development for polymer applications in nuclear power plants. The Polymeric Materials Database for Nuclear Applications is intended to provide a convenient and searchable database of the following:

- Past, current, and potential future uses of polymeric materials for nuclear power plant (NPP) components
- Existing application experience
- Existing materials test data
- Current knowledge gaps that may be impeding the use of polymeric materials in NPPs (relating to materials testing, degradation modes, applicable nondestructive techniques, implementation barriers, and so on)

The database has been partially populated and reviewed by subject matter experts in three polymeric application areas. After further development, the database is intended to facilitate the following:

- Identification of overlaps between knowledge gaps to coordinate future research projects that can efficiently close knowledge gaps for multiple polymer applications.
- Integration of test data and experience for materials used in multiple nuclear applications (such as cables and gaskets) to educate a new or experienced user on polymer uses across multiple applications.
- Collection of knowledge in a single polymer application for experienced users who already work with polymeric components. This resource can then be used to identify knowledge gaps regarding a single polymer application.

After further development, the database presented in this report is planned to be released as an Electric Power Research Institute (EPRI) software product.

Keywords

Aging management
Nuclear power plant
Polymers

EXECUTIVE SUMMARY

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Development of a Database for Polymer Applications

PRIMARY AUDIENCE: Utility personnel responsible for 1) aging management or proactive maintenance of components constructed of polymeric materials or 2) evaluating the use of polymeric materials for new or replacement components; industry personnel responsible for organizing research and testing regarding development, selection, and qualification of polymeric materials for power plant components

SECONDARY AUDIENCE: Engineering staff at nuclear power plants (NPPs)

KEY RESEARCH QUESTION

Polymers have characteristics that are advantageous in potential applications in the nuclear power industry (for example, light weight, corrosion resistant, special surface properties, and low electrical conductivity)., Polymers are currently used for various applications in NPPs, and there are many more potential applications for polymeric materials—particularly in new plant designs and for addressing long-term operations and aging management concerns. Development of current applications and new applications of polymers in NPPs would benefit from integrating research across different application areas and tracking knowledge gaps.

RESEARCH OVERVIEW

For this technical update report, a database was developed and partially populated in order to document polymeric material applications in NPPs. The database structure was designed to capture test environment data, application environment, and existing knowledge on degradation modes, nondestructive examination (NDE) techniques, and implementation issues. After initial development, the database was reviewed individually by subject matter experts in three polymer application areas (cables, coatings, and high-density polyethylene [HDPE] piping), and feedback was incorporated into the database structure.

KEY FINDINGS

- Section 2 presents significant data entry and review by subject matter experts (SMEs) that has been performed in the three polymer application areas of electrical cables, Service Level 1 coatings, and HDPE piping.
- Section 3 includes a detailed explanation of the database structure and fields.
- Examples of how the database can be queried to support a variety of uses are described in Section 4.
- Section 5 includes considerations and recommendations for future developments of the database.

WHY THIS MATTERS

After further development, the database presented in this report is planned to be released as an EPRI software product and can then be used by utility members, EPRI project managers, and other users who work with polymeric materials in order to collect and organize information on polymer applications, to inform research that efficiently closes knowledge gaps across multiple polymer applications, and to integrate polymer material knowledge across multiple applications.

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HOW TO APPLY RESULTS

This database will support aging management of existing polymer components and support new applications of polymeric materials.

LEARNING AND ENGAGEMENT OPPORTUNITIES

- Assessment of current and potential new polymer applications in NPPs: *Program on Technology Innovation: Polymers in Nuclear Power Plants, Current Status and Prospects for Expansion* (EPRI Report 3002005332)
- Existing EPRI databases for polymer applications: *Coatings Option Database Version 2.0* (EPRI 1024604) and *C-PAD 2.0 – Cable Polymer Aging Database, Version 2.0* (EPRI 1011874)
- Ongoing EPRI programs on specific polymer applications (for example, EPRI's Cable Aging Management Program)

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INTRODUCTION

1.1 Background

Research supporting the use of polymers in nuclear power plants (NPPs) is generally driven by one of the following two factors:

- Current applications of polymeric materials in NPPs include some applications that require aging management for continued use, especially during operation past the original licensing period.
- New applications of polymeric materials in NPPs could have significant cost benefits.

With respect to aging management, for example, the U.S. Nuclear Regulatory Commission's (NRC's) Generic Aging Lessons Learned (GALL) report [1] calls for aging management programs for the following polymeric components and systems:

- Boraflex neutron absorbers
- Coatings
- Cable insulation

The increased use of polymeric materials for safety-related components and systems (such as buried piping) for both replacements and repairs is likely to mean that more information on aging management of polymers will be required in the future, especially in light of subsequent license renewal efforts. The interest in evaluating new uses of polymeric materials in NPPs stems from several factors, including the following:

- The current NPP fleet is aging, leading to the need for repairs or replacements of numerous subsystems and components, both large and small.
- The operating experience at NPPs indicates that many applications for which traditional materials of construction (such as metal or concrete) are not optimum.
- The costs of polymeric materials are, in many cases, substantially lower than the costs of more traditional materials (such as metals).
- Recent technological advances (such as the development of advanced composites) have expanded the range of properties that can be obtained in polymers.
- New plants (such as advanced light water reactors) are being built, and new designs (such as small modular reactors) are being developed. These new plants represent opportunities to optimize material selection, including increased use of polymeric materials.

Qualification of new polymeric material applications is anticipated to require extensive research and documentation relating to material properties and testing, fabrication and installation, examination techniques, and so on, depending on the particular application.

In the aging management of metallic components, specifically primary system pressure boundaries for PWRs and BWRs, the Electric Power Research Institute (EPRI) leads the industry in providing the technical bases for optimization of inspections, repair options (including replacement materials), and mitigation options. This effort is managed through the use of the following key resources:

- *Materials Handbook for Nuclear Plant Pressure Boundary Applications (2015)* (3002005470) [2]
- *EPRI Materials Degradation Matrix, Revision 3* (3002000628) [3]
- *Materials Reliability Program: Pressurized Water Reactor Issue Management Tables (MRP-205)* (3002000634) [4]
- *BWRVIP-167NP, Rev. 3: Boiling Water Reactor Issue Management Tables* (3002000690) [5]

The **Materials Handbook** provides a summary of industry experience and research results regarding the use of various metals in pressure boundary applications. It serves primarily as a reference document. The **Materials Degradation Matrix** (MDM) serves to organize the current state of knowledge regarding the degradation of metallic components in PWRs and BWRs. It can be used to quickly identify the status of understanding regarding a particular degradation mode for a specific material or to identify those pressure boundary components that might be subject to common failure modes. The **Issue Management Tables** serve as tools to identify specific knowledge gaps and the component/material/mode combinations to which they apply. This information enables the industry to efficiently allocate resources to close gaps, for example, by using the same research to close similar gaps applicable to different components. The NRC has developed analogous tools, including the **Proactive Materials Degradation Assessment** [6].

The need to document polymer applications and knowledge gaps in a searchable way and the need to integrate polymers research across different NPP operations were raised from the work documented in EPRI Report 3002005332, *Program on Technology Innovation: Polymers in Nuclear Power Plants: Current Status and Prospects for Expansion* [7]. This EPRI report reviews the current uses of polymeric materials in NPPs and other applications (such as power transmission, fossil plants, and aerospace) and identifies potential new uses of polymeric materials in NPPs. The initial concept for a polymer materials database was borne out of the MDM developed for metallic materials. The MDM documents the degradation mechanisms that are applicable to light water reactor plant nuclear steam supply system components and how well the degradation mechanisms are understood and can be mitigated. The MDM has a rigid structure and covers a limited number of well-characterized metallic materials. The structure of the MDM is not amendable to polymeric materials because 1) there are many unique formulations for polymeric materials and composite materials, 2) in some cases, the specific degradation modes are not well understood, and 3) polymeric materials are used in several areas in the plant with largely varying environments. Therefore, in order to facilitate these unique aspects of polymers, the concept of the MDM was expanded to a more flexible database structure, which incorporates the type of information provided in the MDM for metals.

1.2 Polymer Database Objectives

The objective of this project was to develop the framework for a polymeric materials database for nuclear applications providing a convenient and searchable database of the following:

- Past, current, and potential future uses of polymeric materials for NPP components
- Existing application experience
- Existing materials test data
- Current knowledge gaps that may be impeding the use of polymeric materials in NPPs (relating to materials testing, degradation modes, applicable nondestructive evaluation [NDE] techniques, implementation barriers, and so on)

The database is intended to facilitate the following:

- Identification of overlaps between knowledge gaps to coordinate future research projects that can efficiently close knowledge gaps for multiple polymer applications.
- Integration of test data and experience for materials used in multiple nuclear applications (such as cables and gaskets) to educate a new or experienced user on polymer uses across multiple applications.
- Collecting knowledge in a single polymer application for experienced users who already work with polymeric components. This resource can then be used to identify knowledge gaps regarding a single polymer application.

In achieving these objectives, the focus has remained on the two main reasons for interest in polymer research described in Section 1.1, that is, aging management of existing components and supporting new applications of polymeric materials.

1.3 Technical Update Report Structure

This report is structured as follows:

- Section 2 presents the methodology followed in developing the Polymeric Materials Database.
- Section 3 outlines the current structure of the Polymeric Materials Database, including tables and fields.
- Section 4 describes example uses of the Polymeric Materials Database through illustrative query results from the current database.
- Section 5 presents considerations for future stages of development of the Polymeric Materials Database.
- Section 6 lists the references used in development of this report.

2
METHODOLOGY

This section describes the process that was followed in development of the Polymeric Material Database. The process generally involved two stages: first, the initial development of the database structure, and second, review of the database structure and functionality by subject matter experts (SMEs) and subsequent incorporation of review feedback. Each stage of this process is described in detail in the following subsections.

2.1 Initial Database Development

The development of the initial database structure was primarily focused on accomplishing the database objectives outlined in Section 1.2. Along with achieving these objectives, the flexibility and adaptability of the database structure was a high priority in order to capture as many aspects of polymeric material applications as possible initially. The unique aspects of polymers (that is, many formulations and many plant components), as compared to metals, were captured in the structure by creating many database fields to describe details of the material and the application. By breaking down the description of the material and application into many fields, this feature of the design allows 1) the user to provide more detailed information on the application and 2) this information to be searchable (rather than expecting this type of information to be included in a Notes field, where the information may or may not be included and in varying levels of detail, as is done in the EPRI Coatings Option Database).

The Polymeric Materials Database is intended to capture information from a wide range of reference types, not information only from EPRI products. References include material test data reports, application experience reports, existing databases, and aging and degradation research published by a host of organizations, such as EPRI, NRC, International Atomic Energy Agency (IAEA), national laboratories, and many others. A long, but not exhaustive, list of references has been identified for a few polymeric material applications in NPPs. At this time, the database has been populated for only a subset of the polymeric materials references identified, with the focus on those that are most relevant and up to date.

The Polymeric Materials Database is currently being developed in Microsoft Access. Microsoft Access was chosen as the initial platform for database development because of the user-friendly forms that can be created to streamline and standardize the database entry process. However, the data are in a form that can easily be exported to another format and/or be converted to another application. Options for future database formats are described further in Section 5.1.

2.2 Subject Matter Expert Review Process

When the basic database structure was defined and the database was populated by a subset of documents pertaining to a particular application area, the database structure was reviewed separately by three SMEs in cables, coatings, and HDPE piping. The intent of the SME review process was to gather input about the following:

- Unique and/or relevant aspects of the particular polymer application area that are important to capture in the database structure
- Desired database outputs for the particular polymer application
- Other uses for the database (including uses that utilize information across more than one polymer application area)
- Key documents to rank as high importance when querying the database

Section 3.2 summarizes the specific feedback and input that was provided by each of the SMEs and incorporated into the database structure.

3
DATABASE STRUCTURE

This section describes how the Polymers Material Database is structured. The database is composed of two tables—a Reference table and a Main Entry table. Each entry (row) in the Reference table represents a single reference (such as report or database), and the fields in this table describe general aspects of the references that are entered into the database. Each entry in the Reference table corresponds to one or more entries in the Main Entry table. Each entry in the Main Entry table represents one piece of information pulled from a reference. The fields in the Main Entry table generally capture information about a polymeric material application and performance. The two main tables are related by a key field that connects each entry in the Main Entry table to a particular reference in the Reference table. The specific fields contained in the Reference and Main Entry tables are described in more detail in Section 3.1.

For each new reference added to the database, one entry in the Reference table is created and one or more entries in the Main Entry table are created. For each entry in the Main Entry table, the only required fields are the key field identifying the associated reference and at least one other field. Each Main Entry field takes a particular type of input, which include a single selection from a drop down list of options, multiple selections from a drop down list of options, number entry, or text entry. For each entry, as much information as is provided in the reference is added to the database. In cases in which multiple selection drop-down lists are used for data input, all applicable selections are made that apply to that particular entry. In cases when a reference describes, for example, multiple materials (not used in combination) and the performance of each material, a separate entry is made for each material and the associated performance information. Similarly, if a reference describes the ranking of multiple degradation modes for a single material, for example, a separate entry is made for each degradation mode, with the same information entered under the Material fields.

3.1 Definitions of Database Fields

The fields in the Reference table are summarized in Table 3-1 and are defined further in Section 3.1.1. The fields in the Main Entry table are summarized in Table 3-2 and are defined in Sections 3.1.2 and 3.1.3 for the Application- and Performance-Related fields, respectively. In addition, the database contains Administrative fields to capture the initials of the person who made the entry, the initials of the person who checked the entry, and the date on which the entry was made.

Table 3-1
Database reference table fields

Reference Fields	Reference
	Key Category
	Publishing Organization
	Reference Type
	Key Document

Table 3-2
Database main entry table fields

Application-Related Fields	*Material*
	Type
	Additive
	Filler
	Other Descriptor
	Manufacturer
	Product ID/Trade Name
	Application Environment
	Plant System
	General Environmental Grouping
	Maximum Service Temperature
	Radiation (Accumulated Dose)
	Wetted
	Other
	Functional Requirement
	General
	Component
	Rated/Design Temperature
	Associated Material
	Regulated Use Classification
	Safety Related Function

Performance-Related Fields	*Degradation Mechanisms*
	Degradation Mechanism
	Susceptibility Ranking
	Knowledge Ranking
	NDE Techniques
	NDE Technique
	Applicability Ranking
	Capability Ranking
	Test Environment
	Test Type
	Maximum Test Temperature
	Radiation (Accumulated Dose)
	Radiation (Dose Rate)
	Test Exposure Time
	Wetted
	Other
	Known Implementation Issues
	Known Implementation Issue
	Issue Status
	Demonstrated Service Life
	Status of Current Use
	Notes

3.1.1 Reference Table Fields

The references incorporated into this database are further classified by the key category of plant components they cover (based on the categorization of polymeric material applications used in Reference [7]), the type of reference, and the organization sponsoring the publication of the reference. References that were determined to be important, high-level documents in a key category will be identified as such in the Key Document field.

The key categories used to describe references include the following:

- General and miscellaneous
- Piping, tubing, and vessels
- Coatings
- Seals, gaskets, and expansion joints
- Concrete repair
- Cables
- Shielding
- Piping repair
- Spent fuel storage

The reference types incorporated into the database include the following:

- **Application Experience.** References documenting specific application experience (for example, materials used in particular environments, and material/component failures) in NPPs
- **Test Data.** References documenting test and performance results, including environmental qualification tests, LOCA tests, and so on
- **Standard, Specification, and Test Method.** Standards, specifications, or test methods applying to the use of polymeric materials in NPPs and/or specific materials or components and/or condition-monitoring techniques
- **Knowledge Gap.** References identifying knowledge gaps in research
- **NDE Techniques.** References documenting existing NDE techniques or the development and testing of new NDE techniques
- **Degradation and Aging.** References documenting knowledge (or lack of knowledge) on degradation and aging mechanisms and testing to develop knowledge of degradation/aging mechanisms
- **Database.** Databases developed by EPRI
- **Review.** References that review or compile existing work
- **Regulatory Guidance.** References documenting regulatory guidance, including guidance on environmental qualification of components and materials
- **Other Industry.** References primarily focused on nonnuclear (such as power delivery) polymer applications, degradation modes, or NDE techniques

The organizations from which published or associated material is incorporated into this database include the following:

- Electric Power Research Institute (EPRI)
- U.S. Nuclear Regulatory Commission (NRC)
- American National Standards Institute (ANSI)
- Pacific Northwest National Laboratory (PNNL)
- Sandia National Laboratories (SNL)
- Brookhaven National Laboratory (BNL)
- Oak Ridge National Laboratory (ORNL)
- International Atomic Energy Agency (IAEA)
- Japan Nuclear Energy Safety Organization (JNES)
- American Society for Testing and Materials (ASTM)
- Nuclear Research Institute – Rez (UJV)
- Association of Edison Illuminating Companies (AEIC)
- Insulated Cable Engineers Association (ICEA)
- Institute of Electrical and Electronics Engineers (IEEE)
- International Electrotechnical Commission (IEC)

- SKI – Ingemansson Technology (SKI)
- Pacific-Sierra Research Corporation (PSRC)
- Research Institute of Scientific Instruments (RISI)
- Society for Protective Coatings (SSPC)

3.1.2 Main Entry Table: Application-Related Fields

The following general field categories are related to the application and use of materials in a plant environment and/or as a plant component:

- **Material.** Material fields include:
  - Polymeric material type (such as polyethylene)
  - Additives
  - Fillers
  - Other descriptors (such as cross-linked, pink)
  - Material manufacturer
  - Product ID (such as polymer trade name or commercial name).

Chemicals that are added to the polymer blend that react with the polymeric phase (such as bromine or chlorine) are considered additives, while materials that do not react with the polymeric phase of the material (such as reinforcing fibers or materials) are considered fillers.

- **Application Environment.** The Application Environment fields are intended to capture the conditions that a material is exposed to in a specific plant application. Note that several of these fields are similar to those describing performance (see Section 3.1.3). A distinction is made between application and performance data. For example, an entry might include **application** temperature data, describing the temperature in the plant where a particular polymer is used, which is different from **performance** temperature data, for example, the temperature during a laboratory test. Application Environment fields include the following:
  - Plant system (such as condensate system, buried piping, emergency diesel generator, and so on)
  - General environmental grouping (such as treated water, wetted air, air-outdoor, air-indoor/uncontrolled, and so on)
  - Maximum temperature expected to be experienced in service (in degrees Celsius [°C])
  - Radiation, expressed as accumulated dose over the typical operating lifetime (in Mrad)
  - Nonwetted or wetted environment, as indicated as **dry** or **not dry**, where **not dry** includes environments that are wetted, intermittently wetted, or have a relative humidity greater than 60%
  - Other environment descriptors (such as UV exposure, high humidity, and so on)

- **Functional Requirement.** The Functional Requirement fields describe the function served by the polymeric material generally or as applied for use in a specific component. In most cases, the functional requirements of a material are a function of a specified component and specified application. For example, coatings applied in containment (component/application) must adhere to the application surface (functional requirement). Functional Requirement fields include the following:
  - General functional requirement (such as adhesion, chemical resistance, corrosion protection, and so on).
  - Component.
  - Rated/design temperature (in degrees Celsius [°C]) provided by the manufacturer.
  - Associated material (or substrate). This field covers all associated material types that polymers are adhered to, bonded to, or connected to in some way in a particular application. This includes substrates of polymeric coatings or adhesives (such as concrete), materials that seals, gaskets, and expansion joints are used to join, or any other components that are joined with polymeric components (such as HDPE piping to metal piping).
  - Classification of a particular component with regulated use, if applicable. This field includes the applicable ASME code classification or the applicable coating service level classification. The ASME code classification defines the design requirements and quality standards for components that fall under these classes. The ASME code classes include Class 1, Class 2, Class 3, and non-class (which correspond to the NRC definitions of Quality Group A, B, C, and D, respectively). The definition of each class and the systems that fall under each class can be found in Reference [8]. The coating service level classifications are defined in Reference [9] and pertain to the design requirements of a particular coating based on the location of application. Classifications include Service Level 1, Service Level 2, and Service Level 3.
  - Use in safety-related or non-safety-related application(s), which is associated with the function performed by the material and/or component.

3.1.3 Main Entry Table: Performance-Related Fields

The following are the database field categories that relate to the performance of a particular material or component:

- **Degradation Mode.** See Section 3.1.3.1.
- **Test Environment.** The Test Environment fields are similar to the Application Environment fields described previously but relate to conditions experienced during material or component testing. The Test Environment fields include the following:
  - Maximum exposure temperature experienced during test, in degrees Celsius (°C).
  - Accumulated dose over the test period, in Mrad.
  - Dose rate during the test period, in rad/hr.
  - Maximum duration of exposure to test conditions, in days. If accelerated aging techniques are used in testing, the exposure time is likely less than the expected lifetime of the component.

- Non-wetted or wetted test environment, as indicated as **dry** or **not dry,** where **not dry** includes environments that are wetted, intermittently wetted, or have a relative humidity greater than 60%.
- Condition-monitoring test type, that is, the condition-monitoring technique used to assess certain material properties and/or changes in material properties that result from exposure to the test environment. Techniques may be nondestructive or destructive. Common test types include elongation at break, oxidation induction time/temperature, thermogravimetric analysis, gel fraction, solvent uptake, density, modulus profiling, nuclear magnetic resonance, infrared analysis, indenter modulus and recovery time, near-IR reflectance, sonic velocity, torque test, tensile test, oxidation rate, and dielectric loss. ASTM standards and specifications for test methods may be included in this field.
- Other descriptors of the test environment that do not fall into these fields.

In some cases, material testing is conducted with different phases of test conditions. For example, a material is first exposed to simulated normal operating conditions, followed by exposure to simulated loss-of-coolant accident conditions. These test conditions are documented in the database according to the maximum temperature experienced during the test program, the total radiation dose, and the total exposure time to all test conditions.

- **Demonstrated Service Life.** This field indicates the service life demonstrated in the field or in laboratory studies for a particular material-component combination. If a component failure is experienced during operation, the designation **<Design, <40 yrs** is entered into this field, along with the time to failure, if specified. If integrity throughout extended plant operation has been confirmed through testing, the designation **LTO, 60 yrs** or **LTO, 80 yrs** is entered into this field.
- **NDE Techniques.** See Section 3.1.3.2.
- **Known Implementation Issues.** See Section 3.1.3.3.
- **Status of Current Use.** This field indicates the status of current use in nuclear plants and in other industries (such as fossil plants and power delivery) of a polymeric material or material-component combination. The purpose of this field is to distinguish between current and potential applications in NPPs and, for current applications, describe where polymeric materials have been used. This field may specify 1) extent of use in the nuclear industry, 2) use at a particular type of NPP, and/or 3) use at a particular NPP.
- **Notes.** This field is used to include any additional clarifying information that is relevant to understanding the information in the database entry.

3.1.3.1 Degradation Modes

For polymeric materials, degradation modes are often characterized by either the effects of degradation (that is, failure mode) or by the underlying cause of the degradation (because the actual mode of degradation may not be known). An example of a degradation mode characterized by effect is **embrittlement**, while **thermal degradation** is an example of a degradation mode characterized by the root cause. Degradation modes were not redefined in the construction of the database, that is, the degradation modes cited in the references were used as cited without attempting to standardize the definitions. This database includes a comprehensive list of both types of degradation modes, including the following:

- Embrittlement
- Loss of additives/Leaching
- Water treeing
- Electrical treeing
- Ductile failure
- Brittle failure
- Slow crack growth
- Rapid crack propagation
- Failure at joint
- Delamination/disbondment
- Blistering
- Cracking
- Flaking
- Thermal degradation
- Irradiation effects
- Irradiation effects, degradation
- Irradiation effects, cross-linking
- Synergistic thermal and irradiation effects
- Oxidation
- Creep under load
- Melting
- Wear (including erosion)
- UV degradation
- Combustion
- Chemical degradation
- Hydrolysis
- Ozone attack
- Application/installation defects
- Improper fusion
- Fatigue
- Diffusion-limited oxidation
- Corona degradation

- Degradation of electrically insulating properties
- Manufacturing and/or installation damage
- Manufacturing defects
- Voltage stress

For documents that address degradation modes, the status of each degradation mode is evaluated based on the content of the specific document (and is not intended to reflect the current industry status). The status of each degradation mode is ranked based on two criteria: susceptibility and knowledge, as described in the following subsections. The ranking systems were developed based on the Phenomena Identification and Ranking Technique (PIRT) used in the Expanded Materials Degradation Assessment (EMDA), Reference [12]). The details of these rankings are described in Sections 3.1.3.1.1 and 3.1.3.1.2.

3.1.3.1.1 Degradation Mode Susceptibility Ranking

This ranking assesses the susceptibility or likelihood that degradation will occur in service. This ranking typically is associated with a particular material or material-component combination and specified application or test environment.

- Low
  - Not observed in service
  - No evidence that this would be a likely degradation mode
- Medium
  - Potential degradation mode
  - Observed and/or demonstrated in testing, but not necessarily in service
  - Observed in service but has not been replicated in testing
- High
  - Observed and/or demonstrated in service
  - Strong evidence that this degradation mode would occur based on test data

3.1.3.1.2 Degradation Mode Knowledge Ranking

This ranking reflects the understanding of the degradation mode that has been developed through laboratory testing or operating experience. As with the susceptibility ranking, this ranking is typically associated with a particular material or material–component combination and specified application or test environment.

- Low
  - Knowledge gap in understanding degradation
  - Research needed on mechanism and underlying cause
  - Limited data
- Medium
  - Generally well understood
  - Research needed on mechanism or underlying cause
  - Lack understanding of some relevant dependencies

- High
  - Well understood
  - Mechanistic understanding
  - Understanding of all or most relevant dependencies
  - Extensive, consistent data

For any given entry in the database, the knowledge ranking is based on the specific reference on which that entry is based. Therefore, entries based on older references may indicate a lower knowledge ranking than entries based on newer references.

3.1.3.2 Nondestructive Evaluation Techniques

NDE techniques for inspection are considered those that do not require sample removal or those that require removal of only micro-samples from the component for testing, that is, the component can continue to function after inspection. Some NDE techniques are invasive and require contact with the component at the location where the material properties are to be evaluated, while other techniques may have the ability to remotely assess material properties. Nevertheless, the utility of an NDE technique for use with a particular material–component combination is most basically defined by how well the technique evaluates material degradation and the state of development of the NDE technique itself. Therefore, for references included in the database that describe NDE techniques, the status of each NDE technique is assessed in terms of applicability and capability of the NDE technique for inspection of a particular material–component combination. The ranking systems used for applicability and capability are described in the following sections.

3.1.3.2.1 Nondestructive Evaluation Technique Applicability Ranking

This ranking assesses how well an NDE technique can detect degradation or signs of degradation in a material or material–component combination. NDE techniques that fall under each category meet most but not necessarily all of the following criteria:

- Low (not applicable)
  - A low (or no) correlation may have been demonstrated between the NDE technique measurements and degradation.
- Medium (limited applicability)
  - Some correlation may have been demonstrated between the NDE technique measurements and degradation.
  - The technique may be used to detect some degradation modes expected in service, but not all.
  - The ability to assess degradation may be sensitive to component construction or polymer formulation.
  - The NDE technique may serve as only a pass/fail indicator and not show different degrees of degradation.

- High (highly applicable)
  - A strong correlation has been demonstrated between the NDE technique measurements and degradation.
  - The NDE technique is sensitive to different degrees of degradation and does not only serve as a pass/fail indicator.
  - The technique can be used to detect many of the degradation modes expected in service (or certain specified degradation modes).
  - The technique is relatively robust to different environments and different polymer formulations.

3.1.3.2.2 Nondestructive Evaluation Technique Capability Ranking

This ranking serves as an indicator of the technological readiness or the state of technology development. NDE techniques falling under each category meet at least one of the following criteria:

- Low (not applicable)
  - The NDE technique has been identified for potential use.
  - This ranking corresponds to EPRI Technological Readiness Levels 1–3, which include basic technology research and research to prove feasibility [14].
- Medium (limited applicability)
  - The technique is still in development, and significant limitations for implementation may still exist.
  - This ranking corresponds to EPRI Technology Readiness Levels 4–6, which include continuing technology development, early system feasibility in laboratory, and early field demonstration.
- High (highly applicable)
  - The technique is highly developed and has been used in NPPs or in other highly controlled applications.
  - Standards for use as an NDE technique have been developed.
  - This ranking corresponds to EPRI Technology Readiness Levels 7–9, which include prototyping demonstration in an operational environment and commercial deployment [14].

3.1.3.3 Known Implementation Issues

This field is used to indicate concerns or issues associated with polymeric material use that may be barriers to implementations or have regulatory implications. The following are some implementation issues considered in this database. Note that in some cases, different implementation issues are only subtly different from each other, reflecting the diversity of applications and different terminologies developed in different technology areas rather than an underlying technical difference. In these cases, multiple issues are maintained in the database. Users of the database can conduct searches or other database manipulations that combine the following issues or keep them separate, as is most useful to the specific user:

- **Identification of qualified suppliers.** For certain applications, suppliers of polymeric components are qualified on an individual basis. Suppliers that meet qualification standards may be difficult to identify or may be lacking, thereby limiting the application of certain polymeric components.
- **Nominal equivalence.** Many vendors may have slightly different formulations for what is nominally the same polymeric material. As a result, performance or degradation rates may be formulation dependent, leading to difficulties with generically qualifying a polymeric material for use.
- **Proprietary formulations.** Suppliers may have their own proprietary formulation for polymeric materials. Proprietary formulations may contribute to nominal equivalence issues and material qualification issues.
- **Lack of standards and/or specifications for manufacturing.** Standards or specifications to control the manufacturing process may be needed in order to achieve consistent performance results.
- **Lack of standards and/or specifications for field assembly/use.** Standards or specifications to control field assembly or use may be needed to achieve consistent performance results.
- **Lack of standards and/or specifications for application and/or installation process.** There may be a need to develop test methods in order to ensure proper application or installation of polymeric components, especially in the case in which component performance is sensitive to application or installation procedures.
- **Performance sensitive to application and/or installation process.** If the performance of a component is highly dependent on the application or installation process, there may be regulatory issues concerning control of the application or installation process.
- **Difficult application.** Polymeric materials may require difficult-to-achieve application environmental conditions (such as very high temperatures or high humidity) or have characteristics that make them challenging to apply (such as fast curing time). Achieving certain application environments may not be feasible in a plant setting.
- **Difficult-to-control application and/or installation.** Polymeric materials may make it difficult to control the application or installation process of a component in order to achieve consistent performance results. This issue may further lead to regulatory issues in developing standards or specifications in order to control the application/installation process. Examples of polymeric materials with difficult-to-control application may be coating systems with multiple layers that are applied *in situ* or coating systems applied on intricately shaped features, both of which may have varying performance results if the application process is not perfectly controlled.

- **Aging management.** Aging management issues relate to properly accounting for the aging of polymeric components. These issues may relate to inspection, assessment of degradation, and prediction of the remaining useful life of polymeric components, within the design lifetime and for long-term operation.
- **Lack of NDE techniques.** NDE techniques for inspection of polymeric components may not be developed or may be lacking in terms of the ability to detect degradation.
- **Appropriateness of aging model.** Existing aging models may not be appropriate for certain polymeric materials. Effects such as inverse temperature effects and dose rate dependencies may not be accurately captured by existing aging models, which are currently being challenged and reevaluated. This issue may have regulatory implications if the accepted aging models are not conservative.
- **Long-term operation.** Issues may exist with proper operation (or ensuring proper operation) of a component or material throughout an extended plant life of 60 or 80 years.
- **Appropriateness of equipment qualification standards.** Equipment qualification standards are intended to ensure the performance of components in typical operating or accident conditions. Issues surrounding equipment qualification may include lack of knowledge of the actual operating environment, improperly reproducing the aging effects of operating or accident conditions (such as accelerated aging, diffusion-limited oxidation effects, inverse temperature effects, and dose rate effects), or simply lack of conservatism in the standards.
- **Sump-clogging issues.** Concerns may exist regarding obstruction of the containment sump (that is, clogging) in the event that component failure generates debris that may be transported to the containment sump. This issue is documented as NRC GSI 191 [15].
- **Combustible loading.** Many polymeric materials are combustible, and the mass of combustible materials in certain areas with safety-related equipment may need to be considered.

3.1.3.3.1 Known Implementation Issue Ranking

This field is used to indicate the status of a known implementation issue. Issues are ranked on a scale of 1 to 8 that generally reflects an increase in understanding as the number increases. This ranking scale was developed as part of this project. The criteria that are used to rank the status of implementation issues as presented in Table 3-3.

Table 3-3
Status of ranking of known issues (scale of 1 to 8, which generally reflects an increase in understanding as the number increases)

Rank of Status Scale	Issue and Description
1	Issue is determined to be a permanent and unavoidable barrier to implementation.
2	Issue (such as barrier to implementation identified) has been raised, but has not yet been not investigated.
3	Plant experience suggests that issue is not relevant, but no further investigation or research has been conducted to confirm this.
4	Issue (such as barrier to implementation identified) has been raised, and further research in progress.
5	Issue is manageable and avoidable in one particular application but not necessarily in all applications.
6	Issue is manageable and avoidable in most applications.
7	Issue is manageable and avoidable and a theoretical understanding of the issue has been developed.
8	Significant differences in opinion exist on the status of the issue in the industry.

3.2 Input from Subject Matter Expert Review Process

The following sections summarize key topics discussed with the SMEs in the areas of cables, coatings, and HDPE piping. Two generic areas of discussion were 1) unique aspects of the particular application area and 2) application-specific information that would be useful to capture in the database. Based on feedback provided, the database structure was modified accordingly.

3.2.1 Cables

During the review of the database structure as it relates to cables applications, the following concerns were highlighted for cables:

- Many cables have a multicomponent structure, in which one or more polymeric material may be used in combination (for example, the cable jacket and the cable insulation).
- There are contradicting standpoints on regulatory and/or implementation issues among major organizations. For example, organizations disagree on the extent to which certain mechanisms lead to cable degradation.
- Research on cables is extensive, and hundreds of relevant documents present applications, test data, inspection techniques, aging, and degradation mechanisms.

These cable-specific concerns are captured by the database structure as follows:

- If a component (such as cable) contains multiple polymeric materials, these materials can be captured in a single entry by selecting multiple applicable options in the Material fields.
- The status of a regulatory and/or implementation issue is ranked based on the standpoint of a particular reference. If two references present different issue statuses, the database will

contain an entry associated with each reference and its associated status. A database user can then refer to each reference for more information on the reason that a particular standpoint was taken. This part of the database structure also captures the changing status of an implementation issue over time. For example, earlier documents may raise an implementation issue, while more recent documents may present research to help resolve that issue.

- Distinction of **key documents** for each polymer application area is intended to guide users to the more widely known and accepted references in the case that many documents are found for a particular database search.

Furthermore, the review with the cable SME raised the importance of capturing product specification information (such as rated temperature and radiation exposure) in addition to application experience information. For cables, it is important to capture both the **rated** product specifications and the **actual** product performance, because in many cases these can vary greatly. In the case of using the database to identify which type of cabling should be used in a new application, the distinction between the rated and the actual performance specification can be critical.

3.2.2 Coatings

During the review of the database structure as it relates to polymeric coatings, the following concerns were highlighted for coatings:

- Some coating systems contain multiple polymeric coatings applied in layers.
- Some database fields would be of use only for coatings applications such as thickness and designation of coating layers.
- Many polymeric materials used in coatings have limited use in other applications.

These coatings-specific concerns are captured by the database structure as follows:

- As with cables, if a coatings system contains multiple polymeric materials, these materials can be captured in a single entry by selecting multiple applicable options in the Material fields.
- At time of this report, the database does not contain coatings-specific fields (such as fields that would be of use only for coatings applications). However, the database has been constructed flexibly such that new fields can easily be added. The database output can also be altered depending on the type of information that is of interest to the user. For example, the coatings-specific fields may be displayed only if the user is searching for coatings (or if there is a coatings-specific user interface developed).
- Coatings are recognized as a somewhat unique area of polymer applications. Although this coatings-specific concern has not affected the structure of the database, this aspect of coatings may support the utility having a coatings-specific user interface, in which only coatings-related database information would be accessible.

The review with the SME for coatings also highlighted that the application experience and test data contained in the EPRI Coatings Option Database [10] is important information to capture for coatings-specific applications. The EPRI Coatings Option Database is a web-based database constructed from utility input that collects information on coatings applications (such as coating type, location, and so on). The Coatings Option Database also contains PDF links to qualification test reports that support the use of a particular coating in a particular application. Most of the Coatings Option Database fields fit appropriately under the fields in the Polymeric Materials Database. However, the features of 1) PDF attachments to the database entries and 2) frequent database updates by users are not currently amenable with the Polymeric Materials Database structure. At the time of this report, a snapshot of the Coatings Option Database has been incorporated into the Polymeric Materials Database. The consideration of superseding the Coatings Option Database with the Polymeric Materials Database is explained further in Section 5.

3.2.3 High-Density Polyethylene Piping

During the review of the database structure as it relates to HDPE piping, the following concerns were highlighted for this application:

- Most supplier and product names for HDPE piping in nuclear applications are not disclosed in the EPRI-related references in this area. In addition, HDPE formulations are proprietary and change over time and between suppliers.
- As with cables, the area of HDPE piping is highly developed and there are hundreds of relevant documents.

The current Polymers Materials Database structure handles these concerns as follows:

- The database is structured to capture any information about the polymeric material that is provided. In the case that a formulation, supplier name, or product name is proprietary, this information will not be able to be included in the database and the polymer will have to be listed as **high-density polyethylene** (HDPE) (plus any other descriptors that may have been provided on the product, if any).
- As with cables, the distinction of **key documents** will be particularly important for identifying the most relevant and up-to-date documents relating to HDPE applications. In addition, the amount of time that would be needed to import all documents relevant to HDPE piping into the database is unrealistically high. Therefore, it is anticipated that entry of documents that are most applicable to other applications and most helpful to utilities would be prioritized in later stages of this project.

Discussions with the SME for HDPE piping brought up that, looking back on the evolution of HDPE piping at NPPs, a database to capture research and development related to code case development would have improved the development process. This includes capturing both the work that has been done to support code case development (such as testing, design, fabrication and/or installation, and so on) and the gaps that exist in the development effort. Although the code case development for HDPE piping is in its final stages, this use of the database would be applicable to the development of future code cases (for HDPE components or other polymers) or qualification procedures for other types of components (for example, meeting test standards, such as IEEE standards for new cable materials). The current structure of the database allows for much of this information to be captured in a structured, flexible way. An example of how the database can be used to support code case development is shown in Section 4.5.

4 EXAMPLE USES

This section describes several example uses of the Polymeric Materials Database. Sample query results from the database in its current stage of development are used to illustrate the various capabilities of the database. The queried fields and the fields displayed in the output can be altered to suit the intent of the user. This set of sample queries is intended to show only a sample of the database structure and capabilities and does not cover all potential uses of the database. Other miscellaneous potential uses of the database are documented in Section 4.6.

4.1 Example 1: Search Data from Existing Databases

One potential use of the Polymeric Materials Database is to access data from existing databases. The database has been developed with a flexible structure in order to easily incorporate data from sources that already have a structure (that is, databases). At the current stage of development, two databases have been incorporated into the Polymeric Materials Database: the EPRI Coatings Option Database [10] and the EPRI Cable Polymer Aging Database (C-PAD) [11].

As described in Section 3.2.2, the Coatings Option Database is a web-based database constructed from utility input that collects information on coatings applications (such as coating type, location, and component coated). This database serves as a resource to plant personnel to search for coatings options that have been used in a particular plant application (including Service Level 1, Service Level 3, and balance-of-plant components, tanks, and piping). In each plant application, the user can run queries on the database fields. Figure 4-1 shows the output report from the Coatings Option Database for Service Level 3 coatings. Note: All figures in this section are at the end of this section.)

The Polymeric Materials Database can be queried to output the same information that is contained in the Coatings Option Database report shown in Figure 4-1. Figure 4-2 shows how the same information falls within the structure of the Polymeric Materials Database. In addition, the structure of the Polymeric Materials Database allows the user to parse out information that is typically entered in the Notes field of the Coatings Option Database (not shown in the output report). Information that is often supplied in the Notes field includes the coating material type (such as epoxy), coating properties, demonstrated service life, and more information about the application environment. With this information parsed out into different fields, the user then has the ability to conduct searches on this information.

Data from the EPRI C-PAD, which is an installed software product that contains cables insulation and jacket aging data collected from various research labs, has also been added to the Polymeric Materials Database. As was seen for the Coatings Option Database, the structure of the Polymeric Materials Database is amenable to the type of information that is stored in C-PAD, and so the Polymeric Materials Database retains much of the same functionality as C-PAD. The reported purpose of the database is to inform aging models and development of condition monitoring through the collection of thermal, radiation, and thermal/radiation exposure test data.

Figure 4-3 shows an example of the output from C-PAD based on a search for density test data for aged cables with ethylene propylene rubber (EPR) insulation manufactured by Kerite. The corresponding output for the same data contained in the Polymeric Materials Database is shown in Figure 4-4. The Polymeric Materials Database has the additional capability of showing more information on the cable materials of construction (such as the cable jacketing material used in combination with the EPR cable insulation material) in the output. As currently structured, the Polymeric Materials Database does not store test results (such as a measurement made by a condition-monitoring tool). The reporting format and units for different condition-monitoring results vary so greatly (especially across different polymeric components) that the results cannot reasonably be incorporated into the database structure. Rather, it is intended that the database user be guided to the reference(s) that contains any test results of interest using a database query.

These examples of how the Polymeric Materials Database can be used to highlight the ability to incorporate data from existing databases into a single database. Incorporation into the Polymeric Materials Database has the potential to add functionality to existing databases (such as different searching capabilities) and/or expand the usefulness of the data stored in the existing database. Further description of incorporating existing databases into the Polymeric Materials Database can be found in Section 5.3.

4.2 Example 2: Identify Known and Relevant Degradation Modes for Particular Component and Application Environment

Another potential use of the Polymeric Materials Database is to identify known and relevant degradation modes for a polymer used in a particular component and/or application environment. This type of query may be used to identify research needs and priorities (such as direct resources to high susceptibility and low knowledge degradation modes). This type of query may also be used to identify susceptibilities and design concerns for polymers used in new applications. In this case, the database output would inform users about potential degradation modes and in which more information about these degradation modes can be found.

The Polymeric Materials Database stores the status of degradation modes reflected by different references. In all cases, the degradation mode is associated with a polymeric material and, depending on the reference, may be associated with a particular component and/or application environment. Two examples are used here to illustrate the functionality of the database with respect to identifying degradation modes. The first example shows how the database can be used to identify known degradation modes for a particular material and component (such as HDPE piping). A breakdown of the query a user may run is as follows:

- Material = Polyethylene, High-Density
- Functional Requirement: Component = Piping

A sample of the results from this query is shown in Figure 4-5, along with the list of references associated with these database entries. As can be seen in this example, degradation of glass-filled HDPE piping has also been identified.

The second example shows how the database can be used to identify known degradation modes for multiple materials used in a particular component and application environment. A breakdown of the query that a user may run is as follows:

- Functional Requirement: Component = Cable Insulation
- Application Environment: System = Low-Voltage Cables
- Application Environment: Maximum Service Temperature = 45–55°C
- Application Environment: Accumulated Dose = 0.3–3 Mrad
- Application Environment: Wetted = Dry

Figure 4-6 shows an example of the results for this type of query, along with the list of references associated with these database entries. This particular results table reflects the information shown in the PIRT tables presented in the EMDA for cables [12]. The PIRT tables reflect the rankings of potential degradation scenarios for cables based on the judgment of an expert panel. Although the PIRT tables successfully capture the state of knowledge at the time they were developed, the tables will quickly fall out of date as new research is conducted or as research from other sources is considered. The Polymeric Materials Database serves as a way to collect this type of information from all sources and provide updated information if it is available. Both of these examples highlight the following two features of the Polymeric Materials Database:

- Not all fields must be filled in for each entry. For example, no knowledge status for a particular degradation mode needs to be provided. This allows important data to be used even if the reference does not present other factors.
- The same degradation mode for the same material may have a different susceptibility or knowledge ranking across different references (because of differences in opinion, different dates of publication, and so on). When there are multiple susceptibility or knowledge rankings for the same material, all options will be presented in the database output, and the user must decide how to work with the information provided or decide which references are most relevant in a particular case.

4.3 Example 3: Assess Gaps in Test Data for New Applications

The Polymeric Materials Database can also be used to assess gaps in existing test data. This type of search may be used to identify what test data exist for a plant environment expected in a new polymeric material application. As a result of this search, the user is guided to the references that contain existing test data (for more information on the testing details and test results), and the user can identify what testing needs to be completed in order to appropriately assess the materials behavior in the expected plant environment. The Polymeric Materials Database serves as a means to collect test data in a structured format so that the data are easily searchable.

An example of how the database may be used in this way is in assessing which coatings may be acceptable for a new high-temperature application (such as >100°C). A breakdown of the query a user may run is as follows:

- Functional Requirement: Component = Coating
- Test Environment: Maximum Service Temperature (°C) = >100

Figure 4-7 shows a sample of the output that may be expected from the database, displaying only the Material fields and the Test Environment fields. Based on this output, the user can identify 1) which coatings (if any) have been tested at the temperature range of interest and 2) where these test data/results can be found.

4.4 Example 4: Support Nondestructive Evaluation Technique Development

Another potential use of the Polymeric Materials Database is to support the development of NDE techniques for a particular material and/or component. Similar to that for degradation modes, this use of the database would promote focused research efforts on NDE techniques that may have high applicability but low capability. The database also provides a searchable, structured format for gathering references on different NDE techniques and their applications.

An example of query to identify the status of different NDE techniques that are applicable to a particular cable material is as follows:

- Material: Type = Polyethylene
- Material: Other Descriptor = Cross-Linked
- Functional Requirement: Component = Cable Insulation

Figure 4-8 shows an example of the output that results from this type of query (with only relevant fields displayed in the output). This sample output highlights how the database can capture the different applicability/capability rating that an NDE technique may have for the same material used in different components (in this case, in shielded and nonshielded medium-voltage cables). This example also shows how an NDE technique can be given different ratings for the same material/component based on the information presented in different references. Using this output, a user could then identify potential NDE techniques for further research and development and also determine where more information on the current status of these techniques can be found.

As the content of the database is expanded, a similar search could be used to identify NDE techniques that are applicable to multiple materials and/or components, and research efforts could be efficiently applied to closing gaps for a single NDE technique with a range of uses.

4.5 Example 5: Support Code Case Development and Other Qualification Efforts

Another potential application of the Polymeric Materials Database is to support code case development and other qualification efforts for new polymeric component. Database queries can be used to identify where more data or documentation is needed to support qualification efforts. This use of the database was identified as something that would have been beneficial to those who developed analyses that were eventually used in support of the development of ASME BPVC Code Case N-755 for HDPE Piping. It is anticipated that the database could be used to develop supporting analyses for consideration by future code case committees.

Particularly for ASME BPVC code case development, the following seven topics were addressed for the application of HDPE in Class 3 buried piping:

- General requirements (such as scope and responsibilities)
- Materials (material property requirements [and associated test standards], verification testing, repair requirements, quality testing and documentation requirements, and so on)
- Design (design load requirements, temperature requirements, allowable stresses, and so on)
- Fabrication and installation (forming, fitting/aligning requirements, fusion qualification/examination/repair requirements, joint requirements, and so on)
- Examination (applicable examination techniques, acceptance criteria, and so on)
- Testing (pressure testing procedures and requirements, and so on)
- Overpressure protection

These topics are described in more detail in ASME BPVC Section III Appendix XXVI [13]. These seven categories of requirements have already been developed for the construction of Class 3 buried polyethylene pressure piping, but similar efforts are expected to be required for different materials or different applications of HDPE piping. The structure of the Polymeric Materials Database can potentially support this development in the following ways:

- Identify and organize gaps (and research that has been done to fill gaps) relating to fabrication, installation, and examination techniques. These gaps can be captured under the Known Implementation Issues field (such as Lack of Standards/Specifications for Manufacturing, Lack of Standards/Specifications for Application Process, and Lack of NDE Techniques), and the Known Implementation Issues Status field provides further information based on the reference. The list of options for the Known Implementation Issues field can be expanded as needed.
- Specifically for NDE techniques, identify which techniques are best suited for a new application and assess the technological readiness of a particular NDE technique (see Section 4.4). The NDE Technique field and associated applicability and capability rankings can be used to support this type of search.
- Identify standards (such as ASTM or IEEE standards) that apply to a component and should be included in the code case development.

A specific user interface for the Polymeric Materials Database to tailor the database output to track code case development for a particular application may be useful in order to develop in future stages of this project. This user interface could track these bulleted items throughout the code case development process to guide research efforts to close gaps.

In terms of using the database to support qualification efforts in other areas, the Polymeric Materials Database structure is designed to track materials/components that have passed particular test standards (such as ASTM and IEEE) and to organize test data that can be used to develop aging models.

4.6 Other Potential Uses

The following is a list of other potential uses for the database that have been collected throughout the development process:

- Assessment of a polymeric foreign material introduction into a plant system (such as nylon). Assess degradation in plant conditions and potential degradation products.
- Track applications of a particular material and component (such as HDPE piping) in terms of plant, system, regulated use classification, and application environment. Find references associated with each application.
- Assess gaps in test data for currently used components in new application environments (such as HDPE).

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Coatings Option Database

Service Level 3 Report

Manufacturer	Coating System Name	Coating Substrate Application	Surface Preparation	Equipment Application	Environment	Flame Spread Test
	S30P/S30F	Carbon Steel	SSPC SP5	Heat Exchanger	Immersion	No
Carboline	CZ-11 SG	Carbon Steel	SSPC SP10	Diesel Intercooler	Non-Immersion	Yes
	SAR	Carbon Steel	SSPC SP5	Heat Exchanger	Immersion	No
	Arcthane	Other	Other	Heat Exchanger	Immersion	No
Carboline	Plasite 7159	Carbon Steel	SSPC SP5	Tank	Immersion	No
	Belzona 1341 (Supermetalglide)	Carbon Steel		Pipe, Heat Exangers, Flanges	Immersion	No

Figure 4-1
Sample output from the EPRI Coatings Option Database for Service Level 3 Coatings

RefID	*Material*				*Functional Requirement*	*Application Environment*			*Test Environment*	*Functional Requirement*		
	Manufacturer	Product ID	Type	Additive	Associated Material	Other	System	Wetted	Test Type	General	Component	Regulated Use Classification
168	Arcor	Arcor S-30 Primer/S-30 Finish	Epoxy: Novolac		Carbon Steel	Surface Preparation: SSPC-SP 5	Essential Service Water, Heat Exchanger	Not Dry			Coating	Service Level 3 Coating
168	Carboline	CarboZinc 11 SG		Inorganic Zinc	Carbon Steel	Surface Preparation: SSPC-SP 10	Heat Exchanger: Diesel Intercooler	Not Dry	ASTM E84		Coating	Service Level 3 Coating
168	Plastocor	SAR	Epoxy		Carbon Steel	Surface Preparation: SSPC-SP 5	Heat Exchanger	Not Dry			Coating	Service Level 3 Coating
168	Arcor	Arcthane	Elastomer				Heat Exchanger	Not Dry			Coating	Service Level 3 Coating
168	Carboline	Plasite 7159	Epoxy: Polyamine		Carbon Steel	Surface Preparation: SSPC-SP 5	Tank	Not Dry			Coating	Service Level 3 Coating
168	Belzona America	Belzona 1341 (Supermetalglide)	Epoxy		Carbon Steel		Heat Exchanger, Inner Diameter (ID), Flanges, Piping, Emergency Service Water	Not Dry		Non-Wetting, Erosion/Wear Protection	Coating	Service Level 3 Coating

RefID	References	Key Category	Organization	Type	Key Document
168	Coatings Option Database Version 2.0. EPRI, Palo Alto, CA: 2012. 1024604.	Coatings	EPRI	Database	TRUE

Figure 4-2
Sample output from the Polymeric Materials Database for Service Level 3 Coatings

Test Results not shown in Polymeric Materials Database

CableID	TestType	Manufacturer	Material	Function	TestMedium	Expr1	Dose	DoseRate	DoseUnits	Color	TestLab	AgingTime (hrs)	AgingTemperature (C)	Density	StandardDeviation
ZK	Density	Kerite	EPR	Insulation	Air	UConn	0.00E+00	0.00E+00	Rads	Brown	UConn	141.60	132.00	1.31	0.0002
ZK	Density	Kerite	EPR	Insulation	Air	UConn	5.00E+06	1.00E+06	Rads	Brown	UConn	141.60	132.00	1.31	0.0003
ZK	Density	Kerite	EPR	Insulation	Air	UConn	0.00E+00	0.00E+00	Rads	Brown	UConn	566.40	132.00	1.32	0.0005
ZK	Density	Kerite	EPR	Insulation	Air	UConn	5.00E+06	1.00E+06	Rads	Brown	UConn	566.40	132.00	1.30	0.0006
ZK	Density	Kerite	EPR	Insulation	Air	UConn	2.50E+07	1.00E+06	Rads	Brown	UConn	566.40	132.00	1.31	0.0010
ZK	Density	Kerite	EPR	Insulation	Air	UConn	5.00E+06	1.00E+06	Rads	Brown	UConn	847.20	132.00	1.31	0.0005
ZK	Density	Kerite	EPR	Insulation	Air	UConn	0.00E+00	0.00E+00	Rads	Brown	UConn	847.20	132.00	1.32	0.0006
ZK	Density	Kerite	EPR	Insulation	Air	UConn	2.50E+07	1.00E+06	Rads	Brown	UConn	847.20	132.00	1.27	0.0005
ZK	Density	Kerite	EPR	Insulation	Air	UConn	5.00E+06	1.00E+06	Rads	Brown	UConn	1130.40	132.00	1.36	0.0004
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Figure 4-3
Sample output from the EPRI Cable Polymer Aging Database

RefID	*Material*			*Functional Requirement*	*Test Environment*					
	Type	Other Descriptor	Manufacturer	Component	Test Type	Dose Rate (rad/hr)	Accumulated Dose (Mrad)	Max Temperature (C)	Wetted	Max Exposure Time (days)
74	Ethylene Propylene Rubber, Polyethylene	Brown, Chlorosulfonated	Kerite	Cable: Insulation, Cable: Jacketing	Density	0	0	132	Dry	5.9
74	Ethylene Propylene Rubber, Polyethylene	Brown, Chlorosulfonated	Kerite	Cable: Insulation, Cable: Jacketing	Density	1000000	5	132	Dry	5.9
74	Ethylene Propylene Rubber, Polyethylene	Brown, Chlorosulfonated	Kerite	Cable: Insulation, Cable: Jacketing	Density	0	0	132	Dry	23.6
74	Ethylene Propylene Rubber, Polyethylene	Brown, Chlorosulfonated	Kerite	Cable: Insulation, Cable: Jacketing	Density	1000000	5	132	Dry	23.6
74	Ethylene Propylene Rubber, Polyethylene	Brown, Chlorosulfonated	Kerite	Cable: Insulation, Cable: Jacketing	Density	1000000	25	132	Dry	23.6
74	Ethylene Propylene Rubber, Polyethylene	Brown, Chlorosulfonated	Kerite	Cable: Insulation, Cable: Jacketing	Density	0	0	132	Dry	35.3
74	Ethylene Propylene Rubber, Polyethylene	Brown, Chlorosulfonated	Kerite	Cable: Insulation, Cable: Jacketing	Density	1000000	5	132	Dry	35.3
74	Ethylene Propylene Rubber, Polyethylene	Brown, Chlorosulfonated	Kerite	Cable: Insulation, Cable: Jacketing	Density	1000000	25	132	Dry	35.3
74	Ethylene Propylene Rubber, Polyethylene	Brown, Chlorosulfonated	Kerite	Cable: Insulation, Cable: Jacketing	Density	1000000	5	132	Dry	47.1
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RefID	References	Key Category	Organization	Type	Key Document
74	C-PAD 2.0 – Cable Polymer Aging Database, Version 2.0. EPRI, Palo Alto, CA: 2005. 1011874.	Cables	EPRI	Database, Test Data	TRUE

Figure 4-4
Sample output from the Polymeric Materials Database for C-PAD data

	Material			Degradation Mode		
RefID	Type	Filler	Other Descriptor	Degradation Mode	Susceptibility	Knowledge
199	Polyethylene		High-Density	Slow Crack Growth	Medium	Medium
199	Polyethylene		High-Density	Improper Fusion	Medium	
199	Polyethylene		High-Density	UV Degradation	High	
199	Polyethylene		High-Density	Chemical Degradation	Low	Medium
199	Polyethylene		High-Density	Brittle Failure	High	High
201	Polyethylene		High-Density	Irradiation Effects	Low	Medium
201	Polyethylene		High-Density	Slow Crack Growth	Medium	
206	Polyethylene		High-Density	Fatigue	Medium	
206	Polyethylene		High-Density	Ductile Failure	High	
206	Polyethylene		High-Density	Failure at Joint	Medium	
215	Polyethylene		High-Density	Creep under Load	Medium	Medium
215	Polyethylene		High-Density	Slow Crack Growth	Medium	Medium
215	Polyethylene		High-Density	Fatigue	Medium	Low
232	Polyethylene		High-Density	Improper Fusion	Low	High
200	Polyethylene	Glass Fiber	High-Density	Chemical Degradation	Low	High
200	Polyethylene	Glass Fiber	High-Density	Rapid Crack Propagation	Medium	Low
200	Polyethylene	Glass Fiber	High-Density	Slow Crack Growth	Medium	High
200	Polyethylene	Glass Fiber	High-Density	Thermal Degradation	Medium	Low
200	Polyethylene	Glass Fiber	High-Density	Delamination/Disbondment	High	Low

RefID	References	Key Category	Organization	Type	Key Document
199	Balance of Plant Corrosion-The Underground Piping and Tank Reference Guide: Revision 1. EPRI, Palo Alto, CA: 2013. 3002000682.	Piping	EPRI		TRUE
200	Feasibility Evaluation of Glass Reinforced Spiral Wound High Density Polyethylene for Circulating Water System Piping. EPRI, Palo Alto, CA: 2012. 1025297.	Piping	EPRI	Knowledge Gap, Review	FALSE
201	Applicability of High-Density Polyethylene in Nuclear Piping Systems with Internal Radionuclides. EPRI, Palo Alto, CA: 2013. 3002000524.	Piping	EPRI		FALSE
206	Nondestructive Evaluation: Seismic Design Criteria for Polyethylene Pipe Replacement Code Case. EPRI, Palo Alto, CA: 2006.1013549.	Piping	EPRI		FALSE
215	Evaluation of Design Methods for Above Ground High Density Polyethylene Pipe. EPRI, Palo Alto, CA: 2010. 1021094.	Piping	EPRI		FALSE
232	S. L. Abel, et al., "Use of HDPE Piping in the Callaway Nuclear Plant Essential Service Water System," Proceedings of the ASME 2009 Pressure Vessels and Piping Division Conference, July 26-30, 2009.	Piping	ASME		FALSE

Figure 4-5
Sample output from the Polymeric Materials Database for high-density polyethylene piping degradation modes

RefID	*Material*			*Degradation Mode*		
	Type	Other Descriptor	Product ID	Degradation Mode	Susceptibility	Knowledge
2	Polyolefin	Cross-Linked		Any Mode	Low	High
2	Ethylene Propylene Rubber	Flame Retardant		Any Mode	Low	High
2	Ethylene Propylene Rubber, Polychloroprene		Neoprene	Any Mode	High	High
2	Polyethylene, Ethylene Propylene Rubber	Chlorosulfonated		Any Mode	Low	High
2	Silicone Rubber			Any Mode	Low	High
2	Polychloroprene		Neoprene	Any Mode	High	High
2	Polyethylene	Chlorosulfonated		Any Mode	Low	High

RefID	References	Key Category	Organization	Type	Key Document
2	Expanded Materials Degradation Assessment (EMDA) Volume 5: Aging of Cables and Cable Systems, Office of Nuclear Regulatory Research, NRC, 2014. NUREG/CR-7153, Vol. 5.	Cables	NRC	Review, Degradation/Aging, Application Experience	TRUE

Figure 4-6
Sample output from the Polymeric Materials Database for cable degradation modes

RefID	*Material*				*Test Environment*			
	Type	Other Descriptor	Manufacturer	Product ID	Max Temperature (C)	Accumulated Dose (Mrad)	Wetted	Test Type
183	Epoxy: Phenolic		Carboline	Phenoline 305	148.89	0	Dry	Elongation at Break, Density, Elastic Modulus, Tensile
183	Epoxy: Phenolic		Carboline	Phenoline 305	148.89	1000	Dry	Elongation at Break, Density, Elastic Modulus, Tensile
183	Epoxy		Carboline	Starglaze 2011S	148.89	0	Dry	Elongation at Break, Density, Elastic Modulus, Tensile
183	Epoxy		Carboline	Starglaze 2011S	148.89	1000	Not Dry	Elongation at Break, Density, Elastic Modulus, Tensile
183	Epoxy, Epoxy: Phenolic		Carboline	Phenoline 305, Starglaze 2011S	148.89	0	Dry	Adhesion Pull Test, Adhesion G-Value Test
183	Epoxy, Epoxy: Phenolic		Carboline	Phenoline 305, Starglaze 2011S	148.89	1000	Dry	Adhesion G-Value Test
185	Epoxy: Phenolic		Carboline	Phenoline 305	148	0	Dry	Elongation at Break, Elastic Modulus, Tensile
185	Epoxy: Phenolic		Carboline	Phenoline 305	148	1000	Not Dry	Elongation at Break, Elastic Modulus, Tensile
176	Epoxy: Bisphenol A	Diglycidyl Ether			110			Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), Sol-Gel
176	Epoxy: Bisphenol A	Diglycidyl Ether			130			Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), Sol-Gel
176	Epoxy: Bisphenol A	Diglycidyl Ether			150			Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), Sol-Gel
176	Epoxy: Polyamidoamine				110			Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), Sol-Gel
176	Epoxy: Polyamidoamine				130			Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), Sol-Gel
176	Epoxy: Polyamidoamine				150			Fourier Transform Infrared Spectroscopy (FTIR), Differential Scanning Calorimetry (DSC), Sol-Gel

RefID	References	Key Category	Organization	Type	Key Document
176	Y. Zahra, F. Djouani, B. Fayolle, M. Kuntz, and J. Verdu, "Thermo-oxidative aging of epoxy coating systems," Progress in Organic Coatings, 77.2: 380-387 (2014).	Coatings		Test Data	FALSE
183	"Degradation and Failure Characteristics of NPP Containment Protective Coating Systems (U) SRTC Coating System No. 2," Westinghouse Savannah River Company, 2000. WSRC-TR-2000-00340.	Coatings	WSRC	Test Data	FALSE
185	"Degradation and Failure Characteristics of NPP Containment Protective Coating Systems (U) Interim Report No. 3" Westinghouse Savannah River Company, 2001. WSRC-TR-2001-00067.	Coatings	WSRC	Test Data	FALSE

Figure 4-7
Sample output from the Polymeric Materials Database for high-temperature coatings test data

RefID	Application Environment	NDE Technique		
	System	NDE Technique	Applicability	Capability
30	Medium Voltage Cables	Dielectric Spectroscopy	Medium	Low
30	Medium Voltage Cables	Isothermal Relaxation Current	Medium	Medium
30	Medium Voltage Cables	Oscillating Wave Partial Discharge Testing	Medium	Low
30	Medium Voltage Cables	Return Voltage Method	High	Medium
32	Cables: Not Specified	Oxidation Induction Method, Differential Scanning Calorimetry (DSC)	High	Medium
37	Medium Voltage Cables	Dissipation Factor Tan Delta Testing, Frequency Domain Reflectometry (FDR): Line Resonance Analysis (LIRA)	Medium	
105		Indenter Modulus	High	
149	Medium Voltage Cables: Shielded	Dielectric Spectroscopy	High	
149	Medium Voltage Cables: Nonshielded	Dielectric Spectroscopy	Low	
149	Medium Voltage Cables: Shielded	Dissipation Factor Tan Delta Testing	High	
149	Medium Voltage Cables: Nonshielded	Dissipation Factor Tan Delta Testing	Low	
149	Medium Voltage Cables: Nonshielded	Insulation Resistance	Medium	
149	Medium Voltage Cables: Shielded	Insulation Resistance	Medium	
149	Medium Voltage Cables: Shielded	Partial Discharge	High	
149	Medium Voltage Cables: Nonshielded	Partial Discharge	Low	

RefID	References	Key Category	Organization	Type	Key Document
30	Plant Support Engineering: Advanced Diagnostics and Life Estimation of Extruded Dielectric Cable. EPRI, Palo Alto, CA: 2006. 1013085.	Cables	EPRI	Test Data, NDE Techniques	FALSE
32	Reduction of Oxidation Induction Time Testing to Practice as a Life Assessment Technique for Cable Insulation. EPRI, Palo Alto, CA: 1996. TR-106370.	Cables	EPRI	NDE Techniques	FALSE
37	Plant Engineering, Aging Management Program Guidance for Medium-Voltage Cable Systems for Nuclear Power Plants, Revision 1. EPRI, Palo Alto, CA: 2013. 3002000557.	Cables	EPRI	Review, Application Experience, NDE Techniques	FALSE
105	The Final Report of the Project of 'Assessment of Cable Aging for Nuclear Power Plants,' The Japan Nuclear Energy Safety Organization, 2003. JNES Report SS-0903.	Cables	JNES	Degradation/Aging, Test Data	FALSE
149	Plant Engineering: Electrical Cable Test Applicability Matrix for Nuclear Power Plants. EPRI, Palo Alto, CA: 2011. 1022969.	Cables	EPRI	NDE Techniques	TRUE

Figure 4-8
Sample output from the Polymeric Materials Database for cable insulation nondestructive techniques

5 CONSIDERATIONS AND RECOMMENDATIONS FOR FUTURE DEVELOPMENTS

This section presents additional considerations that should be taken into account in future developments of the Polymeric Materials Database. Many of these considerations were raised during initial development of the database but were considered beyond the scope of the effort described in this report. This section informs future decisions regarding the continued development of the database.

5.1 Database Format

The Polymeric Materials Database is currently stored in a Microsoft Access database, which has two main data tables and a form for standardized entry of data (in which most fields have a list of options). A possible ultimate format would be a web-based SQL Server database, which could be easily updated and accessed by all users. The point in development at which the database will transition from a software-based Access database to a web-based database has not been determined. Each of these database formats presents trade-offs between features and cost. The benefit of an Access database is that it is less expensive than a web-based application and would require no effort to convert the data. However, an Access database is a static database that must be re-issued periodically and does not allow users to add new data and instantly have other users access that data. On the other hand, a web-based database can be updated frequently and can be maintained by users directly (if this model is selected, see Section 5.2). Ultimately, to maintain up-to-date and relevant information in the database for the rapidly evolving field of polymers, a web-based application will be necessary in order to provide frequent data updates to all users (regardless of the method by which the data are updated).

5.2 Database Maintenance

The Polymeric Materials Database will need to be maintained in order to keep the database content relevant and up to date. Two central questions must be considered when determining a strategy for maintaining the Polymeric Materials Database: Who will be responsible for updating the database? How can it be ensured that the data are entered in a standardized and complete enough format in order for the data to be useful? Options for updating the database include the following:

- Direct modification. Users (utility members, EPRI project managers, and so on) can add entries directly to the database (only if it is in a web-based format).
- New entry checking process. Users can submit new entries to EPRI to check the entries and then add to the database (for a web-based or software-based database).

Alternatively, direct modification abilities could be granted to only a certain type of user (such as EPRI project managers), while other users will be required to submit new entries through a checking process. The strategy for updating the database directly affects how well the database will be maintained in a standardized and complete format. The data entry process requires some (although minimal) level of orientation in order to properly and thoroughly enter information from a new source. In addition, the searching capabilities of the database rely heavily on the data being entered in a standardized format. Thus, updating the database through direct modification by users increases the likelihood of nonstandardized or incomplete entries. However, the time required to check each new entry may be a nontrivial task.

5.3 Interaction with Existing EPRI Databases

Another important consideration when moving forward with the development of the Polymeric Materials Database is determining how the database will interact with existing EPRI databases (such as the Coatings Option Database and C-PAD). The following questions should be considered for next steps:

- Can subsets of the database supersede existing static databases (such as C-PAD) in which data are maintained in an Access database and are re-issued with new data periodically?
- Can subsets of the database supersede existing web-based, user-updated databases (such as the Coatings Option Database)?

The maintenance strategy for the Polymeric Materials Database directly affects the answers to these questions. If the database is re-issued frequently or updated by users in a web-based interface, existing static databases may benefit from being permanently incorporated into the database. In this case, static databases may be kept up to date more easily than in their original format. For existing web-based, user-updated databases, the databases will benefit from incorporation into the Polymeric Materials Database only if the database is also maintained as a web-based database that is frequently updated. If the Polymeric Materials Database remains as a static database, existing web-based databases will lose some functionality if the database supersedes them.

If the Polymeric Materials Database were to supersede any existing databases, the output from the Polymeric Materials Database could be tailored to present only the relevant data for a particular application. For example, as shown in Section 4.1, the output from the database can be tailored to present essentially the same information as in the output from the Coatings Option Database. For different applications, different user interfaces could be developed to output only subsets of the data from the database.

Another factor regarding incorporation of existing databases into the database is ensuring that no information is lost. Currently, the only information in the Coatings Option Database that cannot be directly transferred to the Polymeric Materials Database is the PDF report link associated with many of the database entries. The current structure of the database directs the user to the Coatings Option Database to access the PDF report link, rather than including the link directly. Adding the ability to attach a PDF or include a URL with each entry in the Polymeric Materials Database is an option that may be considered in future developments. The benefit to linking the reference directly to the database entry is that the user can easily access the data source if they are interested in learning more about a particular entry. A secondary benefit is that information from the Coatings Option Database could be entirely incorporated into the Polymeric Materials Database.

5.4 Recommendations for Future Actions

The following activities may be considered for future development of the Polymeric Materials Database:

- Develop user interface and database maintenance strategy (given the considerations presented).
- Design one or more user interfaces for a subset(s) of the data (for example, only data for a particular application, such as coatings).
- Populate the database for other polymeric applications.
- Resolve data density issues for areas of the database that are populated (that is, identify where data density is low and where higher data density would be beneficial).

6
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