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DEVELOPMENT OF A RELIABILITY DATA TOOLKIT FOR COMPONENT ANALYSIS IN LIQUID WASTE NUCLEAR FACILITIES

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Within the U.S. Department of Energy (DOE) Complex are numerous nuclear facilities which rely on passive and active components to safely control, store, transport, test and process high-level waste (HLW) materials. A major category consists of high-level liquid waste storage, waste processing, vitrification, laboratory and related facilities. These facilities must be safely designed, constructed, and operated in accordance with applicable federal regulations, DOE orders, and DOE standards. To support robust design and safe operation processes, and the related facility Safety Basis, sound reliability data are required. Currently, defensible failure rate data for active and passive components are often not readily available from similar process facilities, difficult to apply because of differences in the operating environment, or are of earlier vintage equipment. A prototype of a Reliability Data Toolkit has been developed to improve the reliability and related data availability for all types of DOE liquid waste nuclear facilities.

The Reliability Data Toolkit focus is initially on failure rate estimates for passive components for various types of postulated liquid waste accident conditions (e.g., pump and valve failure, spray leaks, piping breach). The customized quantitative data informs engineering evaluations, failure modes, effects, and criticality analyses (FMECAs), Safety Integrity Level (SIL) analyses and quantitative risk assessments (QRAs). The implementation of this methodology also allows contractor maintenance and system health organizations to share equipment performance trends, and proactively address potentially affected facilities. While initial baseline data sources include Savannah River Site and other DOE sites and national laboratories, U.S. Nuclear Regulatory Commission contractor reports and other data sets can be implemented as determined by the user in future versions of the software

This paper discusses development of the Reliability Data Toolkit (RDT) methodology, representative trial use applications, and plans for extending the Toolkit in the near-term future.

I. REASON FOR DEVELOPMENT

Component failures in nuclear facilities and the resulting repair operations at liquid waste facilities can cause large schedule, performance, and safety impacts. Replacement of components could result in months of operational down-time and impact facility mission. A Reliability Data Toolkit, referred to as RDT in this paper, would assist with determining the likelihood of component failure, which would inform maintenance program planning. In many DOE high hazard facilities, failure rate prediction is based on generic rates. While they may be developed from a large set of data, there currently isn't a way to account for specific variables that could drastically alter the failure rate. For instance, NUREG/CR-6928 (Ref. 1), which is a major resource for the preliminary development, only provides four failure rates for piping systems. These include external large and small leaks for service and non-service water systems. This toolkit aims to provide the capability of determining specialized failure rates for individual cases. These could include variations in component properties, fluid properties, and other inputs that would impact the estimates. This capability would provide results that are specific to individual components, providing designers, maintenance staff, and other decision makers with a more complete understanding of the risk of failure. This could reduce cost and improve consistency in the application of failure rate data among liquid waste nuclear facilities.

II. METHODOLOGY FOR DEVELOPMENT

This section provides an overview of the methodology used to develop the RDT software model.

II.A. Gather Data

Failure data can be gathered from multiple types of facilities including: waste treatment plants, reactors, and any other facility that records failures and hours of operation. Failure rates would be determined for components in each facility along with all available information about the fluid and component properties. Most facilities have this information, but it isn't readily available or compiled into one database. This data may be kept in paper logs that would need to be examined and extracted. The pertinent information would include the operation time of each component, the fluid properties, the component properties, and the number of each type of failure that has occurred.

II.B. Create Failure Rate Database

The data will then be compiled into a database that can be accessed by the toolkit. This database will contain component specific information that will be used while calculating failure rates. It should be organized by component and each individual failure should be an individual data point in the database, so that accurate correction factors can be determined.

II.C. Determine Correction Factors

The next step is to analyze the data and to determine correction factors for each input. Inputs will include velocity, diameter, pipe roughness, fluid density, viscosity, the effects caused by the differences in Newtonian and Non-Newtonian fluids, and others. If enough data is available, a regression will be performed to determine how each variable affects failure rates. If this data is not available for a specific input, correction factors will be calculated by analyzing previous studies to determine how the variable affects failure rate.

II.D. Create Software

The software is then developed using the failure rate database and correction factors. The failure rate is calculated by taking the component's failure rate from the database and multiplying it by a calculated ratio. This ratio may change depending on the component in question. Ideally, there would be enough data for each component for a regression to be performed to determine each variable's contribution to the component's failure rate. In cases where a sufficient amount of data is not available, the effect of each variable will be accounted for by using established equations relating to wear. For pipes, the friction power loss was calculated from the database information and then for the specific situation. The database failure rate is multiplied by the calculated power loss to database power loss ratio to determine the calculated failure rate. This is explained in further detail in Section III. A similar process can be determined for each component for which performing a regression is not possible. V&V will be performed after the software is created by comparing calculated results to actual data gathered from facilities and to hand calculated values.

III. CURRENT PROTOTYPE

A limited RDT prototype using the methodology just discussed has been developed, and demonstrates some of the desired capabilities. This initial development of the toolkit involved using data from NUREG/CR-6928 (Ref. 1) and EPRI (Ref. 2) in addition to information gathered from multiple DOE facilities. The initial toolkit is limited to the estimation of pipe failure rates and was created using Visual Basic for Microsoft Excel. Table 5-1 in NUREG/CR-6928 provides the failure rate for piping systems, which was derived using commercial nuclear power plant data. The frictional energy loss equation, shown below, is used to determine how each variable contributes to the results.

$$Energy\ loss = \rho g Q h_L \tag{1}$$

ρ = density of the flowing fluid
g = the gravitational constant
Q = flow rate of the fluid
h_L = head loss in the pipe

With the head loss being calculated using the following equation:

$$h_L = f\frac{LV^2}{2Dg} \tag{2}$$

f = Darcy friction factor
L = Pipe length
D = Hydraulic Diameter
V = Fluid velocity

The energy loss was calculated for the database using relevant information for commercial nuclear power plants. The failure rate produced by the toolkit is calculated using the following equation:

$$Failure\ Rate = Database\ FR \times \frac{calculated\ E_f}{database\ E_f} \tag{3}$$

FR = Failure Rate
E_f = Frictional Energy Loss

This calculation is based on the assumption that the energy lost by the fluid is directly responsible for failures in piping components. The user interface for the prototype and most of the inputs can be seen in Figure 1.

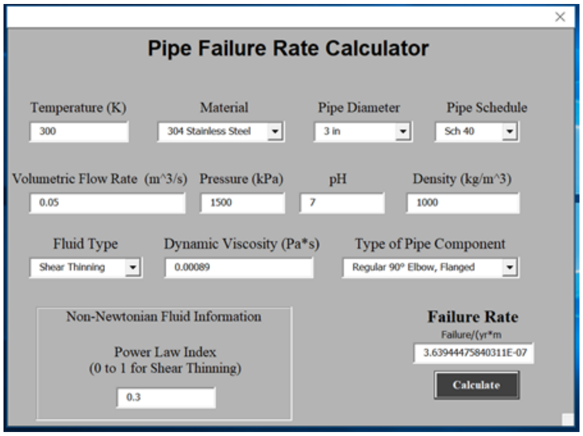

Figure 1 User Interface for Prototype Toolkit

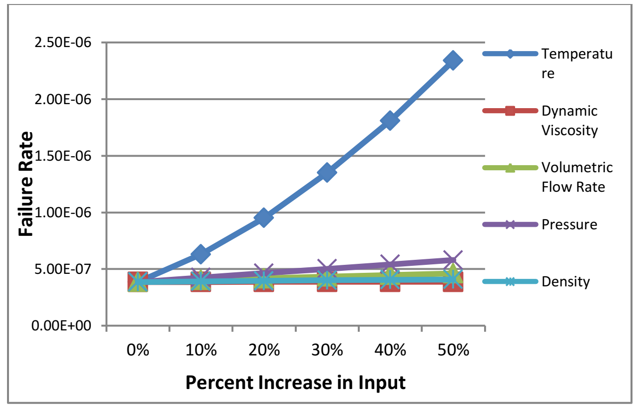

Figure 2 Failure Rate for Increasing Input Values

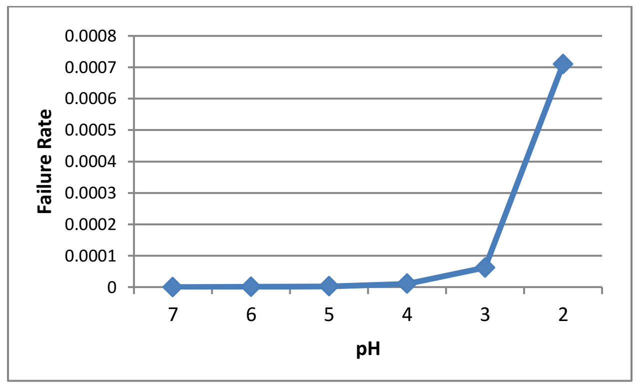

Figure 3 Failure Rate for Decreasing pH

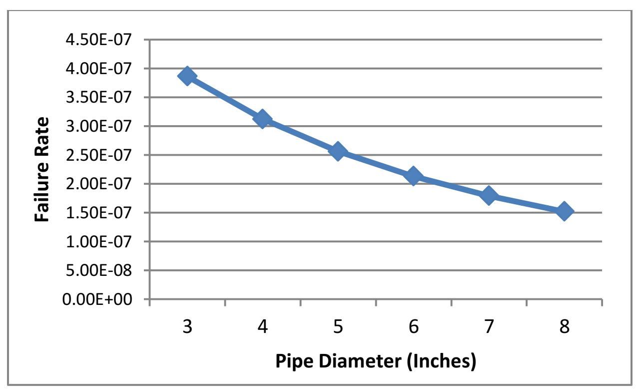

Figure 4 Failure Rate for Increasing Pipe Diameter

<u>Inputs Currently Considered:</u>

The following variables were used as inputs in the prototype. Additional variables will be considered for the final Reliability Data Toolkit as more research is performed.

- Temperature
- Material
- Pipe Diameter
- Pipe Schedule
- Volumetric Flow Rate
- Pressure
- pH
- Density
- Fluid Type
- Power Law Index
- Dynamic Viscosity
- Type of Pipe Component

A sensitivity analysis was performed for these variables. The results are shown in Figures 2, 3, and 4. Figure 2 shows how failure rate increases as each input increases from the baseline value. The failure rate graphs for pH and pipe diameter are shown in Figure 3 and Figure 4. This is valuable information to determine if the software is overly dependent on specific variables. For instance, temperature plays a larger role than any other variable, based on Figure 2. The correction factor equation for temperature will be analyzed as the prototype is revised.

The goal of the prototype toolkit is to be simple and intuitive, while being expansive enough to account for all of the major variables that can impact component reliability. While the prototype is a good representation of the toolkit, it is still limited in its accuracy and functionality. The next step is to begin gathering additional data to develop a more advanced version of the software.

IV. SUMMARY OF THE RDT INITIATIVE & PLANNED EXTENSION

A prototype of the Reliability Data Toolkit has been developed using a simple VBA for Microsoft Excel platform. While currently limited to estimating failure rates for piping and other passive components, the functionality will be expanded to include a variety of active and passive components. This will include pumps, valves, gauges, vessels, and any other components for which failure data is available. RDT provides a consistent and standardized basis for:

- Supporting qualitative estimates during the hazard evaluation and accident analysis process in DOE facilities
- Informing FMECA and (QRA) applications, and
- Identifying key systems for specific types of reliability centered maintenance programs.

As mentioned earlier, gathering data will be one of the most important steps while continuing to develop the software. Anticipated sources include liquid waste facilities at Savannah River, Hanford, and other DOE liquid waste facilities. New data will be used for performing regressions and developing baseline failure rates, as well as determining the accuracy of the RDT's results. Most of this data will have to be compiled from various sources, such as maintenance logs, and then compiled into the RDT database.

V. EXTENSION OF THE RELIABILITY DATA TOOLKIT

Variables that are applicable to the failure of each component will be determined and correction factors will then be calculated for each variable. This can be performed in a similar manner to how the RDT prototype was developed by using a known equation such as the frictional energy loss equation or by deriving a new equation from regression analysis if enough data is available. Following this, the coding language that is the most advantageous for creating the Reliability Toolkit will be determined. In the near-term, RDT may move to a different platform, so that a stand-alone program can be produced. Finally, the RDT will undergo V&V to confirm accuracy and functionality.

FUTURE WORK WITH RELIABILITY DATA TOOLKIT SOFTWARE

In addition to considering other than liquid waste facility application, the authors anticipate application to other nuclear facility types such as laboratory and testing facilities. The RDT could have multiple uses depending on the lifecycle of DOE facilities. It can be used in the initial design phase to determine the failure rate of a proposed design, resulting in improvements to safety, as well being used for established sites to improve maintenance procedures by determining which components are more likely to fail. As the specific uses are determined, the toolkit can be tailored to the facilities that are expected to be studied by adding necessary inputs or expanding the range of values that are available for current inputs. Possible inputs to add or expand include:

- Additional types of Non-Newtonian fluids
- Vibration in the system
- Age of components
- Chemical properties of the fluid and pipe
- Additional component types

The Toolkit functionality will be expanded so that users can input their own data into the database, allowing for more situation-specific failure rates to be developed. This will result in more accurate results that are more applicable to the individual component and facility being analyzed. Ideally, this data can be shared between users so that the database continues to expand. With enough data, the Toolkit could automatically perform a Bayesian update of the database to determine new correction factors each time information is added.

REFERENCES

1. NUREG/CR-6928: *Industry-Average Performance for Components and Initiating Events at U.S. Commercial Nuclear Power Plants, 2007.*
2. EPRI 3002000079: *Pipe Rupture Frequencies for Internal Flooding Probabilistic Risk Assessments, 2013.*