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Lifetime Predictive Capabilities for Materials in the Enduring Stockpile

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Background

A new age has dawned in the history of the US nuclear weapons program. Throughout its early years, the nuclear weapons program experienced continuous weapons development that was supported by underground nuclear testing and a large production complex. Now, however, no new weapon development is currently in progress or envisioned for the near future. Underground testing has been halted and the US has committed to a comprehensive test ban treaty. Many nuclear weapons production facilities have been closed or down-sized. Nevertheless, the US still retains an Enduring Stockpile and has committed to its maintenance and reliability. In the past, predicting age-related problems was not a high priority. In the future, lifetime predictions will be critical to answering the question 'How long can the materials used in weapons in the current stockpile be expected to last?'.

Materials Research

To predict how long a weapon can be expected to last, more understanding of materials aging phenomena is needed. Current and short term materials aging predictive capabilities in each of six different materials research areas have been evaluated. The potential for long term predictions was also assessed. Twenty one researchers from ceramics, energetic materials, metallics, polymeric materials, encapsulants and glass to metal seals responded in 1 to 3 hour interviews. These individuals, with few exceptions, were not the original materials researchers on the design team. A standard set of questions was used that inquired about the current and near term predictive abilities in each materials area, past or current aging studies and critical environments for each type of material. Finally, any information on failure modes for each materials type or analytical models for extended lifetime predictions were requested. Some of the questions that were asked were:

1. What past and current studies have you done related to components?
2. What is the current state of predictive capability?
3. What materials-related inputs do you need to know to make predictions?
4. What environmental inputs do you need to know to make predictions?
5. What future studies related to components do you envision?

Predictive Capability Framework

To better visualize the predictive capability in each research area, a framework was designed to demonstrate the current state of research maturity for each materials area. Figure 1 illustrates the concept of a maturing lifetime predictive capability.

Predictive Capability

Data	Technique	Model	Prediction
Raw Data Indicating a Potential Problem	Accepted Analytical data collection method with Instrumentation	Computational Model based on realistic failure mechanisms and data input	Predictive Capability based on validated computational models

Figure 1. Framework for Materials Predictive Capability Model

The first stage is the existence of raw data that indicates that a problem could exist. The data is not necessarily bounded or taken under conditions that are required for use in a computational model. The next stage of maturity includes a data collection method with an analytical technique utilizing generally accepted instrumentation and methodology. This technique would produce data that would be properly bounded for use in a computational model. Computational modeling, the third stage, requires knowledge of realistic failure mechanisms for each material type and all of the input data required by the mathematical model. The final stage of predictive maturity requires a computational model, all the required input data and validation with experimental samples.

Predictive Capabilities for Aging Materials

A summary of each materials research areas is shown below. Each material type is treated separately with specific information about different categories of materials within each major area. All of the materials research areas required more information to produce more realistic models with proven failure mechanisms. All areas would like to conduct more accelerated aging tests. Predictive capabilities in each of the materials research areas were determined based on the framework and the assessed maturity of the research. Figure 2 summarizes the maturity of modeling and prediction in each materials research area. Although some research areas have matured well into the modeling portion of the framework, all the data necessary for lifetime predictions are not available. The maturity of the research and modeling capability are handicapped by the lack of comprehensive baseline data necessary for prediction. Interfaces offer the greatest challenge to modeling and prediction due to the interaction of two or more different materials. The ability to model failure in bulk materials exists but the relationships and interactions at the interfaces in solders, glass to metal seal and polymer encapsulant interfaces maintains predictive capabilities at a very limited level.

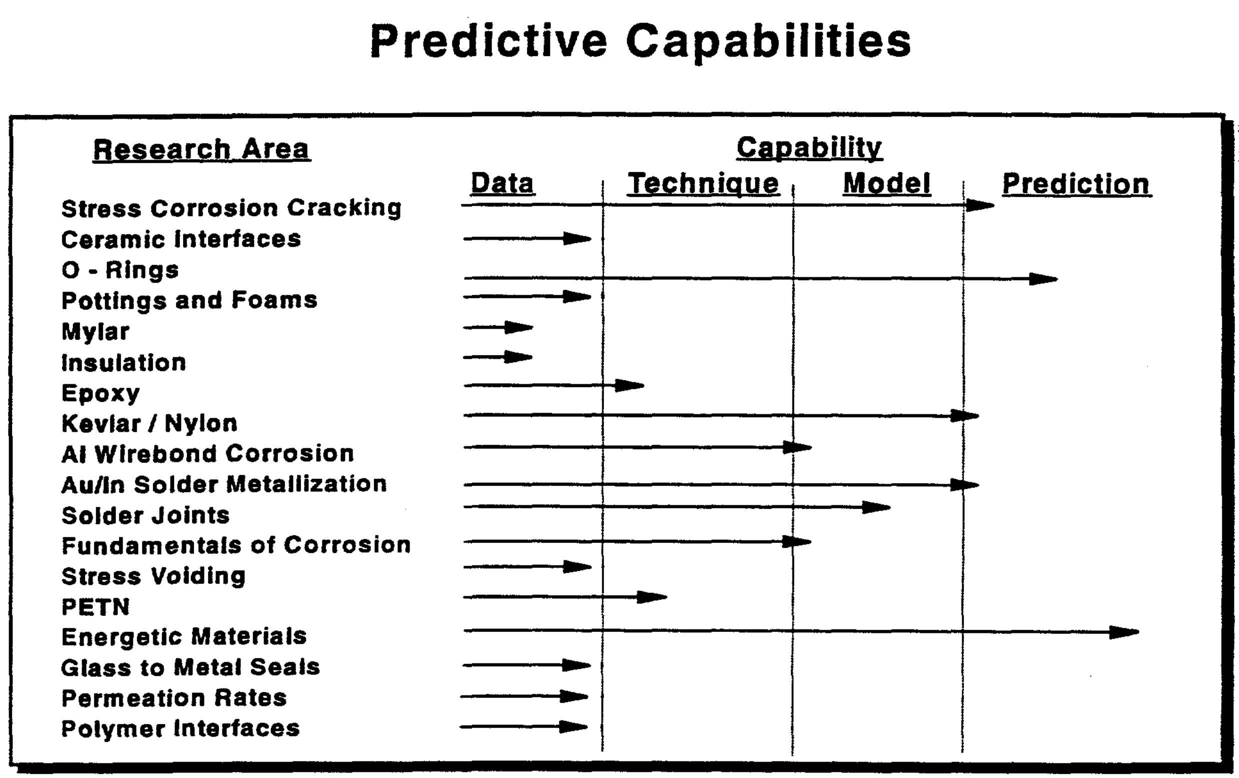

Figure 2. Lifetime Predictive Capabilities for Materials Research

Comparison between Material Research and Component Aging Concerns

In some research areas, the materials aging concerns expressed by the component engineers have already been addressed and lifetime information exists to evaluate component service life. However, in many more areas, the ability to model and predict failures is not mature enough to enable science-based service life extension estimates. Some critical areas where predictive capabilities are lacking are shown in Figure 3 (bold text).

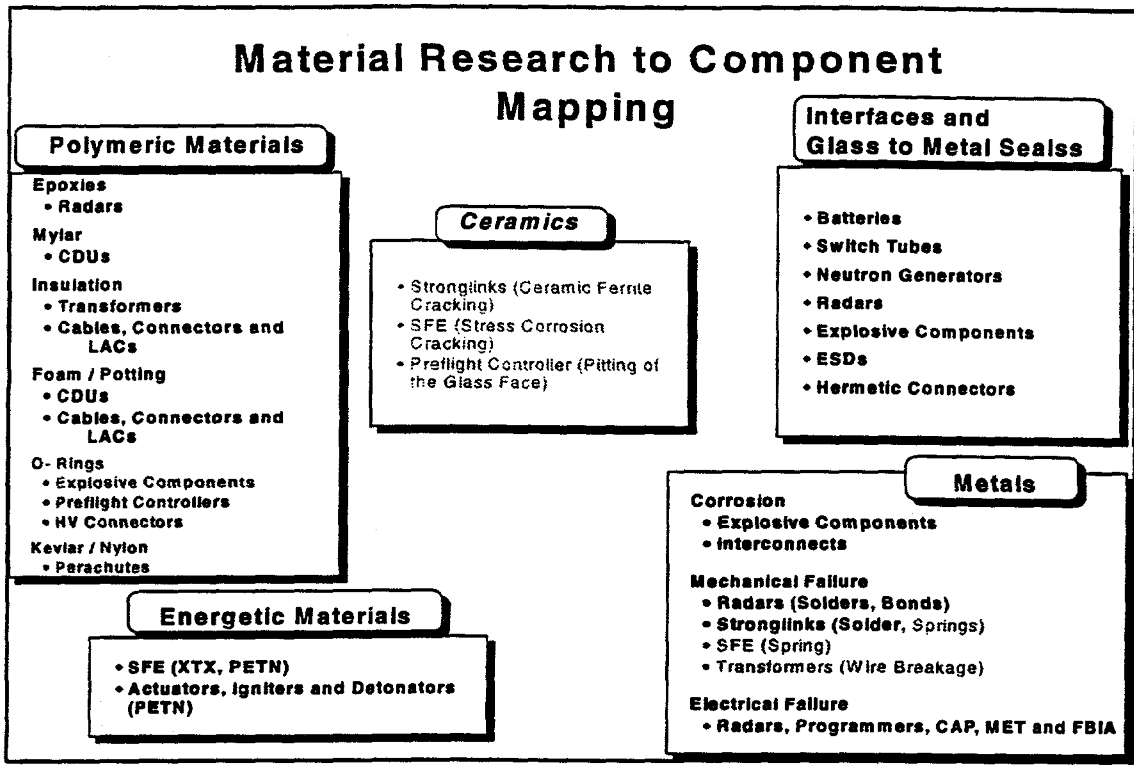

Figure 3. Material Research to Component Mapping

Conclusion

Although materials understanding and modeling is not currently advanced to the point of failure prediction for most critical areas for stockpile components, research should continue to extend the knowledge base and enable science based choices for future programs or upgrades. Several critical areas are lacking for a science-based lifetime extension of the current stockpile.

1. Hermeticity is critical for many components but modeling and predicative capabilities are limited in these areas.
2. PETN is prevalent throughout the stockpile but modeling and predictive capability for autocatalysis and non-hermetic lifetimes is limited.
3. Corrosion is a frequently observed age-related finding from the historical stockpile but the ability to predict the initiation of corrosion is limited.
4. Advanced electronics are in some current weapons types and will most likely be a part of any retrofits and upgrades in the future. Understanding of stress voiding and electromigration in microelectronics is limited and predictions are not yet available.
5. Polymeric materials are prevalent throughout the stockpile and temperature dependent response and mass transport properties are not well understood. Modeling and predictive capabilities for polymeric materials are limited.

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