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POWER REACTOR EMBRITTLEMENT DATA BASE*

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INTRODUCTION

Regulatory and research evaluations of embrittlement prediction models and of vessel integrity under load can be greatly expedited by the use of a well-designed, computerized embrittlement data base. The Power Reactor Embrittlement Data Base (PR-EDB) is a comprehensive collection of data from surveillance reports and other published reports of commercial nuclear reactors. The uses of the data base require that as many different data as available are collected from as many sources as possible with complete references and that subsets of relevant data can be easily retrieved and processed.

The objectives of this NRC-sponsored program are the following:

1. to compile and to verify the quality of the PR-EDB;
2. to provide user-friendly software to access and process the data;
3. to explore or confirm embrittlement prediction models; and
4. to interact with standards organizations to provide the technical bases for voluntary consensus standards that can be used in regulatory guides, standard review plans, and codes.

To achieve these goals, the data base architecture was designed after much discussion and planning with prospective users, namely, material scientists and members of the research staff.

The current compilation of the PR-EDB (Version 1) contains results from surveillance capsule reports of 78 reactors with 381 data points for 110 different irradiated base materials (plates and forging) and 161 data points for 79 different welds. Results from heat-affected zone materials are also listed. Menu-driven software programs have been written to facilitate maintenance, processing, and evaluations of the data. The time and effort required to process and evaluate different types of data in the PR-EDB have been drastically reduced from previous data bases.

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The PR-EDB is designed for use at any personal computer that runs under the DOS system. This feature makes its use independent from large mainframe systems and provides better protection against data corruption and breaches of security than is possible in a centralized system in which many customers have access. Updates will be issued periodically to authorized users. The data files in the PR-EDB are in dBASE format and can be accessed with any version of dBASE or compatible software, such as Clipper. A customized software package that handles most routine tasks has been distributed with the data base and will also be periodically updated.

The Electric Power Research Institute (EPRI), reactor vendors, and utilities are in the process of providing back-up quality assurance checks of PR-EDB and will be supplementing the data base with additional data and documentation. Also EPRI, the BWR-OG Supplemental Material Surveillance Committee, and General Electric have agreed to release the boiling water reactor data for insertion into the PR-EDB. This effort and coordination with the NRC research staff, EPRI, and industry have led to the adoption of PR-EDB as the basis for an industry-wide data base by the EPRI Reactor Vessel Embrittlement Management Project.

DESIGN AND PROCEDURES

The design philosophy behind the PR-EDB is to collect the data in many, relatively small data files that closely mirror the data formats in the surveillance reports and other data sources. This is the main difference from earlier data bases, such as the ones published by MPC, which provide, essentially, one single table. The types of data that will be collected in such a table are predetermined, and each row in the table contains an entry for every data type, leading to a large number of empty entries and duplications. The main problem with this approach is that it requires a major redesign whenever new types of data are to be added to the data base. It is also fairly difficult to accommodate in such a structure multiple determinations of the same quantity, such as chemistry, and to provide complete references, if the data that are combined in the same row come from different reports. In the PR-EDB there is a different input file (raw data file) for each type of data, and the data are transcribed to the appropriate input file directly from the given source material preserving most of the original format, such as units. New types of data can be easily accommodated by simply creating a new file without disturbing the existing ones. Different determinations of the same quantity are simply added as new records and each record is referenced to its source document including page number(s). All data are entered as "characters" (i.e., no numerical format needs to be specified, and special notations such as <0.001 can be accommodated). Blank spaces indicate missing data.

In order to connect data from different files and to identify different determinations of the same quantity, unique "key identifiers" are assigned to materials and reactors. Figures 1 and 2 give a rough overview over the types of data contained in the PR-EDB and how they are connected with the material and reactor keys. In addition, each data set contains a reference identifier that identifies the source of the data. A complete bibliographic listing for each reference identifier is given in a reference file containing author, title,

report number, and time of publication. Extreme care must be exercised in assigning the correct key identifier, otherwise connections between data from different files cannot be made or are made incorrectly. The exacting standards imposed in this way have the additional advantage of repeated cross-checking which reveals many mistakes that had eluded direct proofreading.

Fig. 1. Data related to the material key identifier in the PR-EDB.

Fig. 2. Data related to the reactor key identifier in the PR-EDB.

Conventional proofreading is, of course, applied to all data entries after transcription from the source documents. Additional checks for consistency are made by cross-linking the different raw data files with each other. Mistakes are also frequently detected when the data are processed and analyzed for specific applications, such as the ones mentioned in the section on results. As with any good tool, the PR-EDB improves with use, which in turn requires that such use is encouraged by fast and friendly software. In addition to the in-house data checking, a comprehensive review of the PR-EDB is presently being done by EPRI. Corrected and updated versions of the PR-EDB will be released periodically. Records of all changes and additions are kept in our files. Also, copies of all source documents are collected in our special library.

For any specific application, the data from the raw data files are selected, combined, and put into tables or graphs. Often the data are fitted to a particular model, such as the hyperbolic tangent function, which is used to determine transition temperature and upper shelf energy from a set of Charpy impact tests. To provide the necessary software is a very important part of the PR-EDB program because data alone are useless without convenient tools to process them. Details will be discussed in the section on software. A schematic overview of the data flow in the PR-EDB is given in Fig. 3.

Fig. 3. Data flow in the PR-EDB.

SOFTWARE

All raw data files in the PR-EDB are in dBASE format and can be processed with any version of the original Ashton-Tate dBASE software or any compatible processor, such as Clipper. The latter was used to write a custom-tailored software package that provides the tools for many frequently performed processing steps. The program is menu-driven, that is, the user selects a particular processing step from a number of options displayed on the screen. This minimizes the learning process but is, by its nature, restricted to the more commonly used procedures. Continuing software development will increase the number of choices whenever new applications arise and after feedback from users. Processes that are not covered by the custom software can always be handled by a sequence of dBASE commands (if the user has the necessary expertise).

The following tasks can be performed by the custom software:

1. retrieve and select data from any data files;
2. display selected data to screen, printer, or graph;
3. perform calculations for any combination of data and store results;
4. rearrange data in any specified manner;
5. fit sets of raw Charpy data to hyperbolic tangent functions; and
6. select unique values from multiple determinations of the same quantity (e.g., copper content from several chemistry determinations) and combine selected unique data into special-purpose processed files.

Step 6 has not yet been released; however, it is operational and has been used to obtain some of the results listed in the next section.

RESULTS

The computerized PR-EDB and associated software have been successfully applied to the following three evaluations:

1. *Analysis of the A302B and A533B Standard Reference Materials in Surveillance Capsules of Commercial Power Reactors*, NUREG/CR-4947 (Figs. 4 and 5);
2. *Comparison of Surveillance Data in PR-EDB with "Trend Curves" in Regulatory Guide 1.99, Revision 2* (Figs. 6 and 7); and
3. Comparison of the increase in the brittle-to-ductile transition temperature and the reduction in the Charpy-V upper-shelf energy for specimens fabricated in the LT orientation with those in the TL orientation. The data contain only pairs with the same fluence in the same capsule (Figs. 8 and 9).

Trend Curve for A302B Reference Material Draft Reg. Guide 1.99 Revision 2

Fig. 4. Embrittlement of the A302B reference material relative to the draft Regulatory Guide 1.99, Rev. 2. The upper and lower curves are the 34°F uncertainty bounds (2σ) specified by Regulatory Guide 1.99.

Trend Curve for A533B Reference Material Draft Reg. Guide 1.99 Revision 2

Fig. 5. Embrittlement of the A533B reference material relative to the draft Regulatory Guide 1.99, Rev. 2. The values for HSST01 and HSST03 plates are adjusted relative to HSST02 plate to account for differences in chemistry. The upper and lower curves are the 34°F uncertainty bounds (2σ) specified by Regulatory Guide 1.99.

Fig. 6. Comparison of results from surveillance reports (*plate material*) with the trend curves as given in Regulatory Guide 1.99, Rev. 2. The new data show larger scatter than the original data from which the Regulatory Guide trend curve was obtained, but the scatter appears to be purely random.

Fig. 7. Comparison of results from surveillance reports (*weld materials*) with the trend curves as given in Regulatory Guide 1.99, Rev. 2. The scatter of the new data is of the same magnitude as that of the original data and, as in Fig. 6, purely random.

Fig. 8. Plot of results of a study to determine whether the sensitivity against radiation damage depends on the orientation of the test specimen. [The answer appears to be *negative for transition temperature shift* since the differences show no discernible bias although the scatter is fairly large.]

Fig. 9. Plot of results of a study to determine whether the sensitivity against radiation damage depends on the orientation of the test specimen. [Here a *bias can clearly be seen, indicating a smaller upper-shelf drop in the average for the TL as compared to the LT orientation.*]

FUTURE

The Embrittlement Data Base is designed as a continuing program. This means first of all that any data from new surveillance reports will be added as soon as they are in our possession. In addition, a vast number of test reactor data from the MPC data base, the HSST program, the ORR-PSF program, and experiments at KFA, Juelich, Germany, have been collected and will be integrated to a larger Embrittlement Data Base (EDB). Also collected, but not yet officially integrated, are data from CT and WOL specimen in the surveillance capsules and results from instrumented Charpy tests, including digitized graphic representations of instrumented curves. Detailed results from reactor physics calculations, given in 20 to 47 energy groups, are also available as well as power time histories of many reactors. Such data are important for the study of the dependency of radiation damage on fluence spectra and fluence rates. Only through continuing efforts in the maintenance and updating of data as well as software can the Embrittlement Data Base preclude obsolescence and continue to remain the effective tool for which it was designed.