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THE TEST REACTOR EMBRITTLEMENT DATA BASE (TR-EDB)*

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THE TEST REACTOR EMBRITTLEMENT DATA BASE (TR-EDB)³

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ABSTRACT: The Test Reactor Embrittlement Data Base (TR-EDB) is part of an ongoing program to collect test data from materials irradiations to aid in the research and evaluation of embrittlement prediction models that are used to assure the safety of pressure vessels in power reactors. This program is being funded by the U.S. Nuclear Regulatory Commission (NRC) and has resulted in the publication of the Power Reactor Embrittlement Data Base (PR-EDB) whose second version is currently being released [1], [2]. The TR-EDB is a compatible collection of data from experiments in materials test reactors. These data contain information that is not obtainable from surveillance results, especially, about the effects of annealing after irradiation. Other information that is only available from test reactors is the influence of fluence rates and irradiation temperatures on radiation embrittlement. The first version of the TR-EDB will be released in fall of 1993 and contains published results from laboratories in many countries. Data collection will continue and further updates will be published.

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BACKGROUND

The Test Reactor Embrittlement Data Base (TR-EDB) is part of a NRC sponsored program to create a comprehensive collection of test data that were obtained from neutron irradiations of steel specimen to determine the embrittlement of reactor pressure vessel (PV) steels. The first priority has been the collection of results from surveillance in power reactors since these data are considered most relevant to safety issues in power reactor PVs. However, many issues can only be resolved with data from test reactor irradiations which are less restricted in the number and types of specimen used and in the irradiation environments. Most pressing currently is the need for reliable data on annealing of PV materials since PV annealing is being considered as a means for the extension of power reactor operation beyond design life. Another important issue is the effect of fluence rates on embrittlement to assure that the accelerated fluence rates in test reactors and some surveillance capsules can be applied to the much lower rates in the PV wall and support structures. Also, large CT specimen needed for direct fracture toughness tests can be irradiated only in test reactors.

The scope and purpose of this program, can be summarized as follows:

1. Compile and verify a comprehensive collection of data from test reactor irradiation experiments of pressure vessel materials from U.S. and foreign laboratories.
 2. Provide software support for the use of the data base by furnishing programs and maintaining compatibility with commercially available software.
 3. Maintain compatibility with the PR-EDB.
 4. Maintain compatibility with U.S. and International Standards.
 5. Facilitate the exploration and verification of embrittlement prediction models.
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6. Facilitate the exploration and verification of the effects of annealing for pressure vessel life extension.

A collection of test reactor data was already available in the MPC data base and this collection constituted the starting point for the TR-EDB. These data were traced to the original sources and further information, both old and new, was added. Significant additions came from investigations at the Materials Engineering Associates, Inc. (MEA), the Oak Ridge National Laboratory (ORNL), the International Atomic Energy Commission (IAEA) coordinated research program, and a variety of other irradiation experiments at laboratories in France, Germany, Japan, and the UK. Release of research data from other countries is being negotiated. The origin of each data point is, of course, identified by reference in the data files. The authors of the TR-EDB were provided with copies of the raw data sheets used for the MPC data base. These sheets were prepared by the original investigators and contain some unpublished material, such as, identification of the irradiation facility and pre-irradiation test data. Such data are included in the TR-EDB and identified in the NOTES in addition to the referenced data.

An important difference between surveillance capsule irradiations and test reactor experiments is the way the results are reported. A surveillance capsule report is part of a legal requirement which assures some degree of uniformity and consistency in its content. Test reactor experiments, on the other hand, are designed for specific investigations and the reports, in particular the older ones, present only the data that are deemed relevant to particular questions without regard to their possible use in other research. This is quite understandable given the effort and cost involved in publications, but the reported data are often incomplete. For instance, raw Charpy data are usually presented only as graphs, if at all. Additional difficulties arise whenever the results of the same experiment are reported in different publications without clearly indicating this fact. Frequently different codes are used for the same material or experimental capsule and a considerable amount of detective work was necessary to identify each single experiment or material. (Duplicate entries of this type have been identified in the original MPC Data Base.) For the reasons stated above, verification of the TR-EDB data is difficult and cannot be as thorough and comprehensive as in the PR-EDB. An additional problem is that laboratories and researchers responsible for the published data are often no longer available or cannot be funded for the considerable work involved for outside reviews. All data have been, of course, checked internally

for correctness and consistency and all unresolved problems are reported in the "NOTES." Every effort is being made to resolve discrepancies by contacting the original investigators.

CONTENTS OF THE TR-EDB

The current data collection of the TR-EDB contains primarily Charpy test data which are accompanied in most cases by tensile tests for the same irradiation conditions. Information is available for 1,230 different irradiated sets, 797 of which are from base material (plates and forgings), 378 from welds, and 55 from heat-affected-zone materials. The distribution of fluences ($E > 1.0$ MeV) and irradiation temperatures over these experiments is shown in FIG. 1. Not surprisingly, most irradiations were performed at the typical operating temperature of power reactors around 288°C (550°F) but enough information for other temperatures is available to investigate in detail the influence of irradiation temperature on embrittlement. The chemistries of the investigated materials span also a fairly wide range, particularly, in the content of copper and nickel which are considered the most important contributors to embrittlement sensitivity. Several studies whose results are included in the TR-EDB deal specifically with the influence of chemical composition on embrittlement, primarily copper, nickel, and phosphorus. Complete chemistry information is available for 1,095 of the 1,230 samples (after discarding the HAZ information). The distribution in copper and nickel is shown in FIG. 2.

Most of the test reactor experiments include a few tensile specimen to supplement the information from the Charpy tests. Several experiments also contain compact tension specimen of various sizes as the primary specimen. These data are not currently included in the current version of the TR-EDB. However, work is in progress to collect these data and to design a suitable reporting format so that this information can be included in future releases.

ARCHITECTURE, HARDWARE AND SOFTWARE CONSIDERATIONS

The data format that was chosen for both, the TR-EDB and PR-EDB is dBASE; this format was initially introduced by Ashton-Tate and is now the virtual standard for relational data bases. This format allows queries and data processing not only with the current dBASE software but also with any of the now numerous "Xbase" developer tools, such as Clipper or Foxpro. The dBase files can also be imported into most other database, spreadsheet, and word processing programs which run in the DOS or WINDOWS environment. The more recent versions of these programs contain extensive

FIG. 1--Distribution of Charpy irradiations in fluence and irradiation temperature.

FIG. 2--Distribution of Charpy irradiations in copper and nickel content.

facilities for generating reports including statistic, curve fitting, and graphic programs. For often performed tasks a customized EDB software based on Clipper and FORTRAN has been written originally for the PR-EDB which can be utilized with both data bases. An updated version of these programs is included in the current version of the TR-EDB. No effort is being made to extend the scope of this software any further since commercially available software can be readily applied to the databases for any conceivable application and can also be more readily adapted to Windows and other platforms.

The TR-EDB will be distributed on diskettes suitable for running under DOS on a PC. A 286 system or better is assumed having about 10 Mb free storage on a fixed disk. The file format is compatible with the dBASE software (dBASE III Plus or better), however, many other data base and spreadsheet packages are able to process dBASE files. A custom software package is included with the data which can perform many often needed tasks for processing Charpy and other test data. A floating point coprocessor (287 or equivalent) is needed to perform the calculations and an EGA or VGA capable graphic card for display. A screen capture program is also required for printing of the graphs.

The architecture of the TR-EDB is fully compatible with that of the PR-EDB so that the data from both databases can be easily merged, if desired. (There is some overlap; a few data from the PR-EDB appear also in the TR-EDB to make the latter self-consistent.) However, there are some differences; some changes are due to the differences between power reactor surveillance and test reactor experiments while others are improvements on the first design of the PR-EDB and will be beneficial to both data bases. None of these changes affect the data themselves and the ability to combine and select corresponding data from both data bases. These changes will also not prevent the use of the EDB software package provided for both versions of the EDB.

An overview of the system of files in the TR-EDB is given in FIG. 3. Users of the PR-EDB will note that most of the data files are the same, except for the obvious change of names from PR to TR. There are, however, some additions:

1. The file E_LST_TR.dbf contains a list of the experiments that generated the test reactor data. This information does not appear in the PR-EDB since each surveillance result is uniquely linked to a particular power plant. For test reactor data, on the other hand, it is the experiment that determines the design and goal of the irradiations with the reactor facility only an incidental element. For this reason a new key identifier, EXP_ID, has been added to PLANT_ID in most of the PR-EDB files. (In some files, such as

CHEM_TR.dbf, EXP_ID replaces PLANT_ID.) The file E_LST_TR.dbf contains all relevant information about each experiment, such as, laboratory, principal investigator(s), and location.

2. The file SHFTA_TR.dbf collects results from annealing experiments. To make this information compatible with other materials test data, present and future, a scheme was chosen that assigns a new name to any material after annealing by adding an "anneal tag" to the last four characters of the material identifier HEAT_ID. This allows to list results of materials tests of annealed material together with other data from the same type of tests in one file format. The file SHFTA_TR.dbf contains all the information needed to trace the history of each annealed material consisting of first irradiation, annealing, re-irradiation, re-annealing, etc. This file lists all irradiation fluences, irradiation temperatures, annealing temperatures, and annealing times, plus reactors and capsules involved. Results of Charpy tests as performed at various stages are also included, but tensile tests are listed separately (as are the raw Charpy data). The results of the first irradiations are duplicated in the SHFT_TR.dbf file since these data can be used for embrittlement statistics independent of their later use in annealing experiments.
3. Also added is a file SHFTX_TR.dbf that lists Charpy transition temperatures at other than the standard 30 or 50 ft-lb energy or the 35 mil lateral expansion.

A few minor changes have been made in the structure (i.e., data fields) of the established files. These are mostly improvements which will be implemented in both, the PR-EDB and the TR-EDB. For instance, in the file REAC_TR.dbf a field FLU_TAG was added to indicate the type of fluence determination used for the reported values. Another addition to this file is the field CAP_FISS for reporting the "equivalent fission fluence" which is obtained directly from an activation dosimeter assuming the fluence is a pure fission spectrum. This value is sometimes the only fluence value that is reported in older test reactor experiments. No changes were made in the key identifiers needed for linking different data files so that files from both data bases can be freely combined with each other.

DISCLAIMER

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FIG. 3--Architecture of the TR-EDB.

FUTURE DIRECTION

Data collection in both TR-EDB and PR-EDB will continue. It is hoped that increased cooperation with laboratories outside the U.S. can be established to widen the scope of the collected data. Future releases will also include additional types of test data, in particular results of fracture mechanics tests. Other data types considered for inclusion are instrumented Charpy tests, hardness tests, and drop weight tests; many reports contain this information and data are already on file.

Plans are currently under consideration to archive not only the original data but also the results and procedures of evaluations done on this information. Such a data base can prevent duplications and provide directions for further research. The documentation will involve the creation of evaluated data files, i.e., the selection of data that are suitably transformed and combined to be used in a particular investigation. A second part will be the documentation of the evaluation procedure (e.g., model fitting). For most investigations currently available, spreadsheet software is adequate and earlier investigation can be easily extended and modified by later investigators.

DISTRIBUTION

The distribution of the TR-EDB will be made to all users with the approval of the NRC.

REFERENCES

- [1] Stallmann F. W., Wang, J. A., Kam, F.B.K., and Taylor, B. J., "PR-EDB: Power Reactor Embrittlement Data Base, Version 2," NUREG/CR-4816, 1993.
- [2] Kam, F. B. K., Stallmann, F. W., and Wang, J. A., "Power Reactor Embrittlement Data Base," Proceedings of the Seventh ASTM-EURATOM Symposium on Reactor Dosimetry, p.41-50, Kluwer, Dordrecht/Boston/London, 1990.

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