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Review Process and Quality Assurance in the EBR-II Probabilistic Risk Assessment*

by

J. Roglans, D. J. Hill and W. A. Ragland

Reactor Analysis Division
Argonne National Laboratory

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J. ROGLANS, D. J. HILL, W. A. RAGLAND
Argonne National Laboratory
9700 So. Cass Av.
Argonne, IL 60439-4842, USA

ABSTRACT

A Probabilistic Risk Assessment (PRA) of the Experimental Breeder Reactor II (EBR-II), a Department of Energy (DOE) Category A reactor, has recently been completed at Argonne National Laboratory (ANL). Within the scope of the ANL QA Programs, a QA Plan specifically for the EBR-II PRA was developed. The QA Plan covered all aspects of the PRA development, with emphasis on the procedures for document and software control, and the internal and external review process. The effort spent in the quality assurance tasks for the EBR-II PRA has reciprocated by providing acceptance of the work and confidence in the quality of the results.

I. THE EBR-II PRA

EBR-II is a DOE Category A research reactor located at ANL West in Idaho. It is a Liquid Metal Reactor (LMR), with a maximum power rating of 62.5 Mw-thermal. At full power EBR-II supplies 20 Mw-electric to the Idaho National Engineering Laboratory (INEL) loop. EBR-II started operation in 1964 and it has been used in a variety of research programs, recently as a testbed in the Integral Fast Reactor (IFR) Program. The PRA for EBR-II[1] started in 1989 after the National Academy of Sciences recommended that probabilistic risk assessments be performed for DOE Category A reactors.

The peculiarities of the EBR-II plant have been very important in ensuring the completeness and the quality of the PRA work. First of all, the plant has been in operation for about 30 years and the PRA staff could make use of a considerable pool of experience gathered by the operations personnel. Moreover, some of the staff at EBR-II were involved in the design and construction of the reactor and could provide valuable special insights during the systems modelling.

The experimental mission of the reactor was of the greatest importance in analyzing its behavior under transient conditions, since, in support of research programs, EBR-II has undergone extensive safety analyses that could be called upon in the accident sequence modelling. Furthermore, the safe response of EBR-II to some transient challenges has been confirmed in experiments, like the passive safety tests[2] carried out in 1986 to demonstrate the effectiveness of the passive safety and cooling.

On the other hand, because of the uniqueness of the EBR-II design, the lessons learned from previous PRAs for commercial light water reactors (LWR) could not necessarily be applied to EBR-II. For example, initiating events that are usually of great importance in the light water reactor PRA area, like LOCAs, are almost irrelevant for a sodium cooled reactor of the EBR-II design.

Given the unique EBR-II characteristics and experience, several measures were taken during execution and review of the PRA to ensure the quality of the final product. The major aspects of the quality assurance program can be summarized as follows:

- the PRA was developed at ANL by ANL staff members, many with previous familiarization and experience with EBR-II systems and related safety analysis;

- the systems models and the initiating event characterization were developed with direct input from plant engineering and operations staff, who were involved with the PRA effort from the beginning and, early on, performed a thorough review of the first draft of the system models and notebooks;

- external consultants were used for specific tasks such as fire analysis, human factors, seismicity and seismic fragility analysis and for an overall assessment of the PRA approach and methodology. The consultants were given information about the EBR-II characteristics and its passive safety features;

- a complete review process was undertaken that involved PRA staff members, EBR-II and other ANL personnel, external consultants, and several offices of the Department of Energy.

A system notebook includes a detailed description of the system as well as an analysis of the implications of system failures on the transient behavior of the plant. The system notebooks provide a record of the relation between system design and the PRA logic models and, in this sense, maintaining up to date system notebooks is essential for the concept of a living PRA. As important documentation, the format and contents of the system notebooks are guided by the EBR-II PRA System Analysis Procedure.

II. THE EBR-II PRA QUALITY ASSURANCE PLAN

A Quality Assurance Plan[3] was specifically developed for the EBR-II PRA, within the scope and guidelines of the ANL Laboratory-wide QA Programs. The EBR-II QA Plan was developed at the Reactor Analysis Division and approved by the ANL Quality Assurance, Environment and Safety Office. The Quality Assurance Program is made up of the eighteen elements of NQA-1, and it was designed to apply to all phases of the PRA project. The QA Plan sets forth the methods, controls and procedures, and defines the responsibilities and lines of communication, for activities affecting the quality of the EBR-II PRA. Some of the most relevant elements of the QA Plan are briefly described below.

The first elements of the PRA QA Plan define the PRA organization and structure. The interactions among the groups involved in the PRA Project and with other groups like review organizations and auditors, as they affect the PRA quality, are established. A schematic of the EBR-II PRA organization structure can be seen in Figure 1.

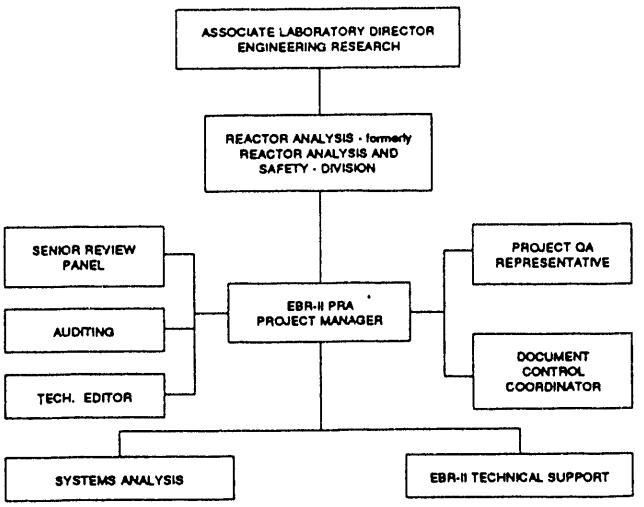

Figure 1. Organizational structure of the EBR-II PRA Project.

The QA Plan establishes the responsibilities of the personnel involved in the PRA and in particular those of the Project Manager and QA Representative. One of the important responsibilities of the QA Representative relates to quality

assurance training of the PRA staff. All EBR-II PRA personnel responsible for activities that could affect the quality of the PRA received the quality assurance training prescribed in the QA Plan and a copy of the QA Plan. Records of the QA training are part of the QA files.

The QA elements and procedures regarding the review of technical work are arguably the most important aspect of the PRA QA Plan, since the review process is considered a key factor in assessing the quality of the PRA. The QA Plan summarizes the guidelines for conducting the PRA review in an evaluation of the PRA work with regard to the following criteria:

- appropriateness,
- correctness,
- adequacy,
- completeness, and
- consistency.

As part of the review of technical work, considerable detail is also provided in the QA Plan regarding the quality assurance of the software used in the PRA. Procedures are given for verification, documentation, and control of the software, whether procured from an external source or developed at ANL. By extension, the software control procedures affect both the computer programs used in the analysis and the models and data stored in electronic format.

The PRA QA Plan also sets requirements for record keeping and document control. The documentation that specifies quality requirements or describes activities affecting the quality of the PRA is placed under control and the QA Plan provides the corresponding procedures. In addition, the PRA document, after all the review steps are completed will also become a controlled document. The QA file was formed to maintain all the records required by the QA Program. The file includes training records, letters of transmittal of the PRA to the review organizations, software development and verification records, cataloged review comments and their resolution, and PRA audit records.

The Quality Assurance Plan covers other items that can affect the quality of the PRA, including purchasing of services (i.e., consulting contracts), minimum requirements of quality assurance records to be maintained, corrective actions systems and procedures for the performance of audits and surveillance.

III. THE EBR-II PRA REVIEW PROCESS

It was recognized from the beginning of the PRA Project that, since the uniqueness of the EBR-II design precluded verification of results by comparison to other PRAs, the most effective way to achieve a high degree of confidence in the outcome was the submittal of the PRA to a thorough and diverse review. The complete review process of the EBR-II PRA involved several steps and a variety of organizations.

The overall approach and methodology that was being used in the EBR-II PRA was reviewed from the beginning of the project by outside consultants with extensive experience in risk assessment. A draft document describing the Systems Analysis Procedures was issued and reviewed by the consultants for appropriateness and applicability to the EBR-II PRA.

The first extensive review of EBR-II PRA work was conducted after completion of the first draft of the systems models and notebooks, labelled Revision 0. This review was performed by EBR-II personnel and was carried out in general on individual basis between the EBR-II systems engineers and the PRA systems analysts. Essentially, this first review aimed at providing an opportunity to involve the engineering and operations personnel more closely in the development of the systems models and the characterization of the initiating events.

After incorporating the input from the EBR-II personnel in the models and completing a first draft of the PRA, Revision 1, a more formal phase of the PRA review process started. This review phase consisted of a fourfold approach, with four different organizations conducting simultaneous reviews of the Revision 1 of the EBR-II PRA. The four groups reviewing the document were:

- the PRA staff, which performed a very detailed review of the overall document, but in particular of the logic models and basic event data;

- an independent external consultant, who had not been familiar with the EBR-II PRA until that time and reviewed all aspects of the PRA work, concentrating on methodology, initiating events and basic event data;

- a senior panel at ANL, with extensive experience in liquid metal reactor safety, which placed emphasis on the PRA approach and the findings and lessons learned; and

- a large group of EBR-II staff members with expertise in a variety of areas ranging from operations to fuel behavior, which performed the most exhaustive review of the Revision 1 of the document.

The choice of review groups was intended to cover all possible aspects of the project. The PRA staff review of the entire document was aimed at assuring correctness and consistency in particular, since the document had been assembled from sections authored by different contributors. Because the systems models had been developed by different analysts, consistency of data sources and values was a critical point to be addressed by the PRA staff during this review.

The external consultant, with expertise in risk assessments rather than LMR safety, provided a critical review of Revision 1 from the PRA methodology point of view. His review addressed in particular the adequacy and appropriateness of the approach and methods. On the other hand, the ANL senior panel, with more expertise in LMR safety, provided an evaluation of the PRA from the point of view of LMR transient behavior. The emphasis of the review of the senior panel was on the correctness and completeness of the models, sequences and results.

Finally, the EBR-II review group evaluated the PRA Revision 1 from all important criteria and naturally provided the most critical examination of the systems models and modelling assumptions. Because several members of EBR-II were already familiar with some of the PRA aspects, the examination provided by the EBR-II group was very exhaustive and of a high level of detail.

To ensure that all the review comments were properly recorded and addressed, a Review Comment form was generated. All comments and suggestions were logged and numbered in review comments forms. There were over two hundred different review comments generated outside the PRA group. The PRA staff consequently started addressing all the comments individually.

Some of the review comments triggered a modification in the logic models or the data values used in Revision 1. All changes affecting the models and data values were correspondingly numbered and logged in a dedicated Change Form. No change took place until written approval by the Project Manager had been obtained. In some cases the PRA staff did not concur with the suggestions of the reviewer, and in such occasions the PRA staff member contacted the reviewer to clarify the PRA position and try to reach an agreement. A small set of review comments required further analysis by the PRA staff, notably the comments provided by one of the original designers of EBR-II, who was consulting for the EBR-II review group.

After all the review comments were addressed and resolved, over two hundred model and data changes had been recorded and approved. The comment resolutions and model and data changes were incorporated to the PRA and Revision 2 was issued. The PRA Revision 2 was submitted to DOE for their review, which is currently under way.

The PRA review process, however, has not concluded with the issuance of Revision 2 and will not finish either after addressing the possible DOE review comments. A mechanism to maintain the PRA updated is in place. Since the EBR-II PRA was first

initiated, several plant modifications have occurred that require the logic models to adapt. Moreover, a program for screening off-normal or unusual events at EBR-II was activated. Plant modifications, occurrences, maintenance and testing actions with possible relevance for the PRA are recorded as review proposals. The review proposals will be addressed when the preparation for Revision 3, after the DOE review is complete, begins. It is expected that the review proposals will result in extensions and changes of the PRA models.

A more ambitious program is planned for the near future, in which the maintenance and testing programs will interact with the PRA. The interaction will be bi-directional, in the sense that maintenance records will provide information to refine component failure data, while the PRA will be used to refine maintenance and testing procedures and schedules with risk reduction criteria. As hardware and procedural changes take place, new PRA revisions will be issued to maintain the document up to date.

IV. SOFTWARE QUALITY ASSURANCE

A key aspect of the EBR-II PRA QA Plan is software quality assurance and control. The QA Plan extends the concept of software control to both the computer codes used in the PRA calculations and all the systems models and data. The systems models and data have been stored in electronic form to facilitate its integrity and control. Indeed, a considerable effort has been devoted in the EBR-II PRA to ensure quality of the PRA codes and data.

The computer codes used in the PRA include blocks for fault tree editing, plotting, and analysis, accident sequence and bin analysis, event tree plotting, seismic PRA analysis, and a set of database utility programs. The PRA data covers event tree and fault tree logic models, initiating events, and basic event information. The approach selected to manage the computer codes and data consisted in creating a centralized electronic database. It was determined that a centralized database would meet all the data protection requirements while at the same time providing easy access and reporting capabilities in a multi-user environment.

A commercially available relational database management product, ORACLE™[4], was selected for creating the EBR-II PRA database. The application was conceived to be user friendly, with all the user interfaces consisting of menus, on-screen forms, and utility programs that control the user access and the validity of the operations requested. The database was installed in the network of Unix workstations operated by the Reactor Analysis Division at ANL-East and is fully accessible to the EBR-II personnel at ANL-West. A maximum of 16 users can simultaneously access the database. The entire database application is fully portable to any other computer platform operating ORACLE.

The code portion of the database contains the source coding used in the calculations of the Revision 2 of the PRA. The fault tree analysis and fault tree drafting portions of the computer code were ANL modifications of existing codes, MODULE[5] and TREDRA[6], respectively, while the remaining codes were developed entirely at ANL. A test and verification program, as indicated in the QA Plan, was undertaken. A standard test case was generated to verify the different parts of the code whenever changes (in either the coding or the computer system) occur. The computer codes were verified by comparison with similar codes commercially available. After testing and verification, the PRA codes were placed under configuration control in the PRA database. A specific configuration control procedure was written to regulate the control and integrity of the codes.

The PRA data that is stored in the database currently contains data for Revisions 1 and 2 of the PRA, comprising over 75 event trees, with over 400 accident sequences, about 250 fault trees with a total of 1200 logic gates and more than 1300 basic events. In addition there is a variety of miscellaneous PRA data, such as basic event data sources, naming convention tables, and auxiliary information. The initial loading of PRA data in the database was carried out after completion of the Revision 1 of the

PRA, when all the models and data from the different analysts were centralized. To verify the database loading and structure, a full repetition of the calculations of Revision 1 was repeated with information retrieved directly from the database. Revision 2 calculations were performed exclusively with logic models and data directly supplied by the database.

Additional information, not requiring the strict control necessary for the source codes and the PRA data, has also been stored in the database for convenience and completeness. This information consists of the review comments and review proposal records, their resolution, and off-normal or unusual occurrence records at EBR-II. Although these records are originally generated in paper form, their storage in the database permits easy tracking of the status of the comments and proposals, as well as the convenience of having all the PRA information in a single package. For this last reason, the feasibility of storing the entire PRA document in the database is currently being evaluated.

A two-level protection limits access to the database, namely password-controlled access to the Unix network and a further password-controlled database account. Access and use of the database can be audited and unauthorized use can be easily detected. A complete procedure for periodic multi-media backups and checks of the database contents is in place. The diverse backup procedures allow for disaster recovery, as well for full recovery of the database to the status at important past milestones such as a particular PRA Revision.

Users have only read permission to the information their task requires, and new database entries can only be realized by a designated database manager. The process for making new entries involves the request and approval for a code or data change or addition. The signature of the staff member requesting the database change and the signature of the Project Manager are needed before the change can be effected.

When code or data changes, additions or updates are made in the database, old or obsolete entries are never overwritten. This feature enables the creation of a living PRA, in which the evolution of the system models, data, and PRA codes, not only their latest version, is readily available. The database has a number of built in checks for new data entries that guarantee conformance with the naming convention and sufficiency of the data supplied.

V. CONCLUSION

The development and application of the EBR-II PRA Quality Assurance Plan required a considerable effort, but it has been instrumental in providing a high degree of confidence in the quality of the final product. Equally important, the heavy involvement of the EBR-II engineering and operations personnel in the performance of the PRA and more particularly in the review process that was established for the PRA has resulted in a high level of acceptance by plant staff of the EBR-II PRA as a tool. This acceptance is not only desirable, but essential for the EBR-II PRA to become a living PRA that is routinely used to analyze certain plant situations or in support of hardware or procedure modifications. This is indeed the case at EBR-II where requests for applications of the PRA or PRA techniques have been forthcoming since the completion of the Revision 2[7].

Added benefits of the overall QA Plan established for the PRA are the ready access to the different sets of data and models used in the calculations, the ability to easily monitor the evolution of the codes and data, and the high standing of protection and control over the codes and data. The EBR-II PRA has been audited twice and, while some improvements have been proposed, the present QA Plan has been found highly satisfactory.

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