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IDENTIFICATION AND MANAGEMENT OF PLANT AGING AND LIFE EXTENSION ISSUES FOR A LIQUID-METAL-COOLED REACTOR*

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INTRODUCTION

Experimental Breeder Reactor II (EBR-II) is a pool-type sodium-cooled fast reactor that supports extensive experimental, test and demonstration programs while providing electrical power to the local grid. EBR-II is a U.S. Department of Energy Facility located at the Idaho National Engineering Laboratory and operated by Argonne National Laboratory (ANL). The current mission of EBR-II is to serve as the operational prototype for the Integral Fast Reactor demonstration program. This mission and other programs require EBR-II to operate reliability to a 40-year lifetime, a significant extension beyond the five to ten year life originally planned for the facility. The benefits of operating EBR-II in the extended-life mode are important for providing long-term operational performance data for a sodium-cooled fast reactor that is not available elsewhere. Identification and preliminary assessment of potential life-limiting factors indicate that, with appropriate consideration given in the design phase, the sodium-cooled plant has potential for a very long operational lifetime. Achievement of a 40-year lifetime with high reliability is important not only for achieving the near-term goals of the EBR-II/IFR programs, but for the advancement of the liquid-metal-cooled reactor concept to the demonstration/commercialization phase. Key features make extended-life operation feasible based on the use of sodium as the primary coolant: low-pressure, high thermal capacity primary system and a low-pressure secondary system requiring no active valves; and limited corrosion of components.

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IDENTIFICATION OF KEY PLANT AGING AND LIFE EXTENSION ISSUES

As the EBR-II facility was approaching 20 years of operation in the early 1980's, programmatic commitments required reliable operation to at least 30 years. ANL began a process of identifying and evaluating aging, reliability, and life-extension issues that could preclude achieving the operational goal, and developing plans for assuring reliable extended-life operation.

In order to accomplish this, a complete engineering and operational assessment of all major and most minor plant systems was performed by a special task force.

This assessment resulted in a list of critical components that were judged to have the most potential to preclude or otherwise inhibit the ability of the plant to operate reliably to 30 years. The critical components list included primarily components within or directly associated with the reactor and primary systems. The criteria for making the list included the potential for failure or malfunction of the component to cause a plant shutdown of three months or longer; and the potential for the component to significantly reduce plant reliability. The critical components list is shown in Table 1.

In addition to the engineering and operational assessment, other work was ongoing that, while directed toward research and development programs, had direct application and benefit to the plant-life extension effort. This work included thermal stress and cyclic fatigue studies for major components, and reactor material neutron radiation damage studies and tests. These projects provided the analytical and material testing support required to establish a technical basis for extended life operation.

Table 1

Critical Components List

Nonreplaceable or Nonrepairable	Replaceable or Repairable
Safety Rod Drive System	Control Rod Drive System
Reactor Grid-Plenum Assembly	Fuel Handling System (in-tank)
Rotating Plugs/Seals*	• Core gripper
Primary System Instrumentation	• Holddown
Primary Tank	• Reactor Cover-Lift Mechanism
Reactor Vessel Neutron Shield	• Fuel Storage Basket
	• Fuel Transfer Arm
	Primary Sodium Pumps
	Intermediate Heat Exchanger
	Reactor Building Polar Crane

The cyclic fatigue study included thermal stress and creep analyses of the reactor vessel, vessel cover, intermediate heat exchanger, primary piping, superheaters, and secondary sodium piping. The analyses were performed to ensure that these major components could safely withstand a series of transient tests planned for the facility. The most highly stressed component was identified for each of the transient series. The limiting component overall based on allowable thermal cycles was identified to be the intermediate heat exchanger. However, the cumulative cycles at 30 years of life, including transient testing, was still less than half of the allowable cycles based on ASME code criteria. In addition, the intermediate heat exchanger is a replaceable component.

*Considered nonreplaceable.

Neutron radiation damage studies and in-reactor tests have been performed since the early days of EBR-II operation. Surveillance samples of different reactor materials were installed in the reactor core, blanket, and reflector regions in surveillance subassemblies in the mid-1960s to study the effects of a high-energy neutron environment on structural reactor materials. The materials of most interest were Type 304 stainless steel representing the reactor grid plate, reactor cover, reactor vessel, and primary tank; and the reactor vessel neutron shield (graphite sealed in 304 SS canisters). The significant age-related concerns for these materials were loss of ductility of the nonreplaceable components, void swelling of the grid plate, and swelling of the graphite shielding that surrounds the reactor vessel wall inside the primary tank.

The grid plate and graphite shielding were identified to be of primary concern when considering plant life extension because of their nonreplaceable nature and susceptibility to neutron damage due to their proximity to the core. Some of these irradiation samples were located in regions of the core that have a higher neutron flux than the grid plate and graphite shield are exposed to. Thus, in 20 years the samples reach a neutron fluence equivalent to the grid plate fluence at 45-50 years of operation. Tensile tests of the 304 SS material samples have indicated that residual ductility remains well above reasonable allowable minimums, and void swelling is low. Likewise, tests performed on the irradiated graphite samples indicate that the graphite is in a densification phase and has not yet started to swell at these fluences.

From the results of these assessments, analyses, and tests, indications were that the reasonable expected technical lifetime estimate for EBR-II was well beyond 30 years and closer to 50 years before approaching any aging limits. Also, with the newly defined mission of operation as the IFR prototype during the 1990s, and other new programs coming into the facility, it became important that EBR-II be able to operate reliably to a 40 year lifetime (1964-2004). With that as the goal, the plant-life extension program was refocused to build upon the original results of the plant engineering and operational assessment, and emphasize much more the technical evaluations of the irradiated materials samples in order to established the minimum useable lifetime of the nonreplaceable components to provide additional technical bases to support operations to a minimum of 40 years.

In consideration of a 40 year lifetime, the Critical Components List continues to be a focal point for direction of resources for surveillance, diagnostics, preventive maintenance, spare parts, and upgrade modifications for improving long-term reliability. The major component thermal stress and cyclic fatigue analyses have been updated to consider 40 years of operation. The updated analyses indicate that with very conservative assumptions, the limiting component (intermediate heat exchanger) will have accumulated only 60% or less of the allowable lifetime cycles. As indicated above, some of the irradiated materials samples examined already have accumulated neutron exposure to establish physical property characteristics beyond the 40 year operational life. Other irradiated material samples are undergoing examination and testing to add to the material database. Of particular interest are irradiated samples of the primary tank weld material. Even though the primary tank is exposed to much lower neutron flux than the grid plate and reactor vessel wall, the effects of long term exposure to high temperature sodium in addition to the neutron flux require further evaluation.

In the balance of plant, the issues associated with the aging and life extension are not considered to be as critical because of the accessibility and maintainability of both the secondary heat transport system and the steam system. Both the secondary and steam systems are nonradioactive. The secondary system uses sodium as the heat transport medium, resulting in a simple, low pressure system with no valves in the main loop and a highly reliable electromagnetic pump with no moving parts. The steam generator (superheater and evaporators) have proven to be highly reliable. Other power-producing sodium-cooled reactors have experienced difficulties with steam generators, but the duplex tube design used in EBR-II has been very reliable.

Furthermore, an EBR-II superheater was removed from service in the late 1970's after a degradation in heat transfer efficiency was experienced; and replaced with a modified evaporator.[1] The superheater was destructively examined and found to be in excellent condition. The sodium side had little or no evidence of corrosion or erosion, and the steam side exhibited normal effects of exposure to saturated and superheated steam. The heat transfer degradation was determined to be the result of relaxation of the pre-stress of the mechanically bonded duplex tubes. The other superheater had metallurgically bonded duplex tubes and has not experienced any degradation.

MANAGING AGING AND LIFE-EXTENSION ISSUES

The identification and characterization of the key plant aging and life-extension issues is the first and most important part of managing these issues. Once this process has been completed, then plans for managing plant aging and life extension become, in most cases, relatively straightforward. A factor that must be considered in these plans is the possibility that a key aging mechanism or life-limiting factor has been overlooked or underestimated. This is particularly true in a reactor with unique design features.

Management of plant aging and life extension issues at EBR-II consists of the following elements: (1) a formal surveillance program for all critical systems that brings together system experts from the Engineering, Operation, and Maintenance departments on a regular basis to investigate and document system performance to look for problems or other operational anomalies that may indicate near term or long term degradation; (2) an inservice inspection program that includes visual, ultra-sonic, radiography inspection of the secondary and steam/feedwater piping systems, and gauging of the reactor grid plate to check for neutron-induced void swelling effects; (3) a material irradiation, testing and evaluation program to continue to take reactor materials to neutron exposure well beyond that expected for reactor components at 40 years; (4) a plant modification program to replace or upgrade major electrical components, and instrumentation and control systems; (5) provision for removal and repair or replacement of major primary system components including ensuring availability of major spares (intermediate heat exchanger, control rod drives, primary pump shaft and impeller); (6) application of advanced diagnostic techniques to monitor plant and system performance to detect and identify symptoms of long-term degradation[2]; (7) evaluation of plant aging and life extension issues and their relationship with the critical systems and components identified in the EBR-II Probabilistic Risk Assessment Report; and (8) continued line management emphasis, cognizance, and evaluation of plant life extension related issues, both programmatic and technical.

Management of the EBR-II plant aging and life extension program is being accomplished in three phases (Table 2). Phase I (1982-1985) included the engineering and operational assessment of all major (and most minor) systems and components in the plant, development of the Critical Components List, and providing a list of near term and long-term recommendations directed toward assuring long-term reliable operation of the facility. Phase II (1986-1990) includes detailed evaluation of critical reactor component material properties for extended-life operation, evaluation of major component stress levels and fatigue damage to determine allowable duty cycles and residual lifetime margin, and documentation of the results of these evaluations to establish the technical basis for extended-life operation to 40 years. Phase III (1991 →) consists of replacing and upgrading major components where reliability and spare parts availability have or will become a problem, identification and planning for future upgrades, and full implementation of the plant surveillance and trending program that emphasizes long-term degradation detection. Phase III also continues reactor material irradiation and evaluation.

Table 2

EBR-II Plant Life Extension Program

1982-1985 Phase I	1986-1990 Phase II	1991 → Phase III
"30-Year Study"	40-Year Plant Life Assessment	Integration of PLEX Considerations into Technical Support Activities
• Operational & Engineering assessment of EBR-II to identify factors which could limit operation to less than 30-years	• Identify & evaluate key aging/degradation mechanisms of critical components	• Develop replacement schedule for aging components
• Published Report: "Extending Operational Lifetime of EBR-II to 30 Years and Beyond"	Develop estimates of residual life for critical components	• Establish funding requirements
		• Identify in 5-year plan
	• Establish the technical basis for operation of EBR-II to a 40 year lifetime	• Continue material irradiation and evaluation
• Developed interface with commercial facilities and other DOE Category A reactors on PLEX programs	• Publish technical basis document	• Expand surveillance, monitoring, trending activities directed toward long-term degradation detection.

CONCLUSION

Identification and management of the key aging and life-extension issues for the long-term operation of EBR-II has taken on renewed importance with the advent of the IFR program and the role of EBR-II as the operational prototype for the IFR. Extension of the EBR-II operating lifetime to 40 years is a significant step beyond the originally planned lifetime of ten years or less. Certain features of EBR-II make this a feasible goal based primarily on the use of sodium in the primary and secondary heat transport systems (low pressure, low stress, low corrosion) and certain design features. The aging factors of most concern continue to be evaluated and characterized with an inservice inspection program, archive material irradiations, and continuing critical component evaluations. Identification and management of other aging and life-extension related factors continue as part of ongoing surveillance, trending, and diagnostic programs. Periodic upgrade of major plant systems (where feasible) is another key element for reliable extended life operation.

It appears that there are no inherent factors that would prevent EBR-II from achieving the 40 year goal, but continuing attention to identification and management of aging and life-extension factors will remain a top priority.

REFERENCES

1. H. W. Buschman, et al., "Operating Experience of the EBR-II Steam Generating System," ASME Publication 81-JPGC-NE-4, Joint ASME/IEEE Power Generation Conference, St. Louis, MO, April 1981.

2. R. W. King, J. E. Mott, and W. H. Radtke, "Application of Pattern Recognition Diagnostic System to EBR-II Plant Life Extension," Proceedings of the ANS/ENS International Conference on Nuclear Power Plant Life Extension, Snowbird, UT, August 1988.