# ENCLOSURE 2

# MFN 06-120

**Non Proprietary Version**

# NEDO-33243, "ESBWR Marathon Control Rod Nuclear Design Report," May 2006

GE Energy
Nuclear

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eDRF 0000-0002-8100
May 2006

**LICENSING TOPICAL REPORT**

# ESBWR MARATHON CONTROL ROD NUCLEAR DESIGN REPORT

## PROPRIETARY INFORMATION NOTICE

This is a non-proprietary version of the document NEDE-33243P which has the proprietary information removed. Portions of the document that have been removed are indicated by open and closed double brackets as shown here [[ ]].

## IMPORTANT NOTICE REGARDING CONTENTS OF THIS REPORT

**Please read carefully**

The information contained in this document is furnished **for the purpose of supporting the NRC review of the certification of the ESBWR**, with the information here being used as ABWR supporting reference. The only undertakings of General Electric Company with respect to information in this document are contained in contracts between General Electric Company and any participating utilities, and nothing contained in this document shall be construed as changing those contracts. The use of this information by anyone other than that for which it is intended is not authorized; and with respect to **any unauthorized use**, General Electric Company makes no representation or warranty, and assumes no liability as to the completeness, accuracy, or usefulness of the information contained in this document.

# Table of Contents

## List of Tables

## List of Figures

# 1 Introduction

The control rod selected for the ESBWR design is a Marathon blade [Reference 1] with $B_4C$ as the absorber (neutron poison) material. Since the equilibrium core design for ESBWR was performed with an S-lattice Duralife blade, the Marathon blade was designed such that its initial cold worth matched that of the Duralife blade. The B-10 poison in the blade was depleted as a function of time to determine the level of depletion that would reduce the blade worth in a quarter segment by 10%. This constitutes the end-of-life (EOL) of the blade. These depletion fractions are converted to EOL fluences to facilitate plant monitoring. The peak absorber tube heating rate is also provided. The final set of calculations involved developing axial profiles for blade depletion including the determination of peak rod depletion data.

The procedures outlined in NEDE-30931 [Reference 2] are generally followed in these analyses. The three-dimensional Monte Carlo radiation transport code, MCNP01A [3], a GE ECP, was the principal tool used in this work. The following sections detail these calculations and present results.

# 2 Methodology

## 2.1 Depletion Methodology

The blade worth is defined as $1-k_{con}/k_{unc}$, where $k_{con}$ and $k_{unc}$ are the controlled and uncontrolled multiplication factors, respectively.

The blade lifetime is defined as the point in time when the cold worth of a quarter segment of the blade is 10% less than the cold worth at the beginning of life (BOL) of the blade. The standard way of presenting the blade lifetime is as the EOL thermal fluence in units of snvt (sextillion or $10^{21}$ neutrons/cm$^2$), which is derived from the EOL depletion fraction. In order to obtain the depletion fraction, a set of runs is made with MCNP01A, where the removal rate of the poison in the absorber tubes is held constant for a period of time. Using this reaction rate, a new set of atomic densities is calculated and used to update the MCNP input and the code runs again. The depletion calculations are performed at hot 40% void conditions. At each time step a calculation is also performed at cold conditions. The cold $k_{con}$ at each time step is used to determine the worth and reduction in worth from BOL. This process is continued for several time steps and a depletion profile vs. worth is established. It is assumed that the fuel is in a fresh condition throughout this depletion process. In the present analyses, 30 time steps of 100 days each were taken. The standard depletion equation for B10 is given as

$$\frac{dN_{B-10}}{dt} = -(N * \sigma)_{B-10} \qquad (1)$$

Here, $\sigma$ is the reaction rate per unit nucleus obtained from the MCNP run at each time step ($\Delta t$ in width) and the new atomic density $N_{B\text{-}10}$, is given as

$$N_{B-10} = N_{B-10,prev} * \exp(-\sigma \Delta t) \quad (2)$$

Once the depletion fraction equivalent to a 10% worth reduction is determined, the following procedure is used [Reference 2] to convert this into the EOL thermal fluence in snvt.

A quantity called the percent B10 depletion per unit snvt is defined as

[[

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Thus, the EOL thermal fluence in snvt is given as
[[

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## 2.2 Heating Rate

The limiting heating rate (in units of W per g of $B_4C$) in the blade occurs at BOL conditions. The heating rate calculations at BOL are conservative since the heat generation rate decreases with the blade depletion. The heating rate is calculated using the value of $\mu$, the ratio of the average absorptions in the poison in the blade to the total fissions in the node (see Section 2.1), the average energy deposited in the poison per absorption via the (n,$\alpha$) reaction (2.79 MeV), and the total number of fissions in the node determined using the power density. In addition to the average value, the heating rate in the peak absorber tube is also determined using the radial peaking factors across the blades. For the heating rate calculation the limiting value is at BOL and this radial profile is used to determine the peak rod heating.

## 2.3 Axial Depletion

Control rod nuclear lifetime, as described in Section 2.1, is defined as the depletion limit corresponding to a 10% reduction in the cold worth from BOL conditions. The mechanical lifetime is defined as the total average depletion that corresponds to the allowable helium pressure limit in the limiting absorber tube. The rod with the highest burnup is determined by using the depletion profile radially across the blade. An average profile over the blade lifetime (equivalent to 10% reduction in worth) is used to determine the average peak rod depletion since this is more representative over the blade lifetime. This combined with a limiting axial profile will provide the average peak rod depletion.

The main assumption used in these analyses involves the use of existing nominal (typical) and limiting (worst-case) EOL axial burnup profiles that were developed for BWRs and ABWRs. The control blade is shorter [[ ]] in the ESBWR and the profiles for the shorter blade are not developed. Therefore the [[ ]] profiles are assumed to be valid for the short blade. It must be noted that these profiles were developed as a standard set applicable to all BWRs and have been used over the years for various blade designs in their current form.

The standard normalized axial profiles for the nominal and limiting are presented in Table 2.1. The nominal profile is top-peaked and typically represents a core where standard blade patterns are used over the operating cycle. The limiting profile is flatter and is seen in cores operating with the control cell core concept, where a few blades see deep-shallow exchanges over the cycle. The mechanical limit can be adjusted by removing some of the absorber material at the bottom of the blade and creating a plenum region. The standard profiles are plotted in Figure 2.1

## 2.4 Computer Codes and Calculational Model

MCNP01A [Reference 3], is a fully qualified code that is based on MCNP4A [Reference 4] and is a continuous energy Monte Carlo radiation transport code. The cross section set used is from the ENDF/B-V library [Reference 5]. The combination of MCNP and ENDF/B-V has been qualified for use in Light Water Reactor calculations [Reference 6,7]. The code was run in iterated source (criticality) mode with 2 million histories typically leading to standard deviations in the critical eigenvalue of approximately 0.0005.

The model was run with a single bundle with the surrounding water gap with the ESBWR nodal pitch of [[ ]]. Fully reflective boundary conditions were used. Continuous energy cross section sets at the appropriate fuel and moderator temperatures were used including the correct bound-scattering data for hydrogen in water. Each fuel rod is individually modeled with two concentric rings of fuel pellet and cladding. The control blade model includes the individual absorber tubes (square tubes) and the tie-rod. A GE14 10x10 lattice with an average enrichment of [[ ]] in U235 and [[ ]] Gd rods of [[ ]] was used for the analyses. This was the main lattice type in the predominant bundle in the ESBWR equilibrium core.

Figure 2.2 shows the lattice used for the analyses. The enrichment values shown in this figure translate as [[ ]] w% U235 [[ ]] etc. The rods shown with entries 45 through 51 are Gd rods with [[ ]] w% U235 and [[ ]] w% Gd. The water rods are shown with entries of -77. The control blade will be located in the left and top water gaps.

Figure 2.3 shows the MCNP model with the blade. It must be noted in Figure 2.3, that the lattice in Figure 2.2 has been rotated counter clockwise by 90°.

The blade dimensions used in the analyses are presented in Table 2.2. The radius of curvature of the tie-rod is [[ ]] where as the analyses used a radius of [[ ]]. This difference was also shown to have a negligible effect on the final results.

## Table 2.1 Nominal and Limiting B10 Burnup Profiles

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**Table 2.2 Blade Dimensions used in Analyses**

| Description | Dimension | |
|---|---|---|
| | (inches) | (cm) |
| Span | [[ | |
| Half Span | | |
| Blade Thickness (Square Tube Width) | | |
| Half Blade Thickness | | |
| Tie Rod Half Thickness | | |
| Radius of Central Support Tie Rod | | |
| Span of Central Support (Tie Rod) | | |
| Half Span of Central Support | | |
| Inner Diameter of Tube (Capsule) | | |
| Number of B4C Tubes (Capsules) | | |
| Number of Hafnium Rods | | |
| Number of Empty Tubes | | ]] |

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**Figure 2.1 Nominal and Limiting Axial Profiles**

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**Figure 2.2 Lattice Used in Analyses**

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**Figure 2.3 MCNP Model of Lattice with Blade**

# 3 Depletion Calculations and EOL Fluence

The depletion calculations were performed using [[ ]] steps each of [[ ]] days in duration. Since the blade is fairly uniform in the axial direction, a set of calculations was performed with all absorber tubes filled with $B_4C$. Since the absorber tube tolerances are of the order of [[ ]], three sets of calculations were performed: nominal diameter of [[ ]], lower tolerance of [[ ]], and upper tolerance of [[ ]]. In addition to the cold eigenvalues, hot 40% void eigenvalues are also presented. Tables 3.1, 3.2, and 3.3 present the results for the nominal, lower, and upper tolerance absorber tube diameters. The change in cold worth from each of these tables is plotted against the B10 depletion percentage and the data fitted. Using the fit, the depletion percent equivalent to a 10% worth reduction is determined. The plots, with the fits, are in Figures 3.1, 3.2, and 3.3, for the nominal and upper and lower tolerance diameters, respectively.

Using these depletion fractions, the EOL fluence is calculated using equations 3 and 4. A summary of the EOL depletion fractions and fluences are presented in Table 3.4

Table 3.1 Depletion of the Marathon Blade: Nominal Absorber Tube

| Equivalent B10 Depletion (%) | Cold Eigenvalue (k) | Sigma | Cold Worth (Δk/k) | Change in Cold Worth | Hot Eigenvalue (k) | Sigma | Hot Worth (Δk/k) | Change in Hot Worth |
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## Table 3.2 Depletion of the Marathon Blade: Lower Tolerance Absorber Tube

| Equivalent B10 | Cold | Sigma | Cold | Change in | Hot | Sigma | Hot | Change |
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**Table 3.3 Depletion of the Marathon Blade: Upper Tolerance Absorber Tube**

| Equivalent | Cold | Sigma | Cold | Change | Hot | Sigma | Hot | Change |
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**Table 3.4 Marathon-End of Life Fluence**

| Case | 10% Reduction in Cold Worth | |
|---|---|---|
| | Depletion % | Fluence (snvt) |
| Nominal diameter | [[ | |
| Lower Tolerance-diameter | | |
| Upper Tolerance-diameter | | ]] |

[[

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**Figure 3.1 Marathon Blade-Nominal Diameter Depletion Curve**

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**Figure 3.2 Marathon Blade-Lower Tolerance Diameter Depletion Curve**

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**Figure 3.3 Marathon Blade-Upper Tolerance Diameter Depletion Curve**

# 4 Blade Heating Rate

The radial relative burnup profiles across the span of the blade for the three diameters are presented in Table 4.1. The data presented in Table 4.1 are an average of profiles at 5 different burnup steps. However, these profiles are insensitive to the burnup of the blade. The data also indicates that these profiles are insensitive to the size of the absorber tubes.

The heating rate is calculated as described in Section 2.2. Table 4.2 presents the heating rate for the three different absorber tube sizes.

**Table 4.1 Marathon Normalized Radial Burnup**

| Radial node | Normalized Radial Burnup Profile for Different Tube Diameters | | |
|---|---|---|---|
| | Nominal diameter | Lower Tolerance diameter | Upper Tolerance diameter |
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**Table 4.2 Marathon Blade Heating Rate**

| Case | μ-value | Average Heating (W/g of $B_4C$) | Peak Tube Heating (W/g of $B_4C$) |
|---|---|---|---|
| Nominal- diameter | [[ | | |
| Lower Tolerance-diameter | | | |
| Upper Tolerance-diameter | | | ]] |

# 5 Axial Depletion of Blade

The typical axial depletion profiles discussed in Section 2.3 were used in combination with the radial depletion profile to establish the average depletion fraction in the limiting rod. The limiting rod is the rod at the outer end of the blade. These analyses were performed assuming that all the tubes are filled with absorber material over the entire length of the blade. In the final design this rod will be empty for about [[ ]] from the bottom of the blade. Thus these results present the bounding depletion rates. Tables 5.1, 5.2, and 5.3 present results for the nominal and upper and lower bound diameters of the absorber tubes, respectively.

The nominal tube diameter case has a peak average EOL B10 depletion of approximately [[ ]] in the limiting tube. Since the mechanical limit is approximately equal to [[ ]] depletion and this value exceeds this limit, the plenum region at the bottom is introduced to accommodate the released helium gas and provide pressure relief within the tube.

**Table 5.1 Marathon Nominal Diameter: Axial Percent B10 Depletion Profiles for 10% Worth Reduction**

| Axial Node | Normalized B10 Depletion Profiles | | Quarter Average B10 Depletion (%) | | Blade Average B10 Depletion (%) | | Limiting Absorber Tube B10 Depletion (%) | |
|---|---|---|---|---|---|---|---|---|
| | Nominal | Limiting | Nominal | Limiting | Nominal | Limiting | Nominal | Limiting |
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| 24 | | | | | | | | |
| Average | | | | | | | | ]] |

**Table 5.2 Marathon Lower Tolerance Diameter: Axial Percent B10 Depletion Profiles for 10% Worth Reduction**

| Axial Node | Normalized B10 Depletion Profiles | | Quarter Average B10 Depletion (%) | | Blade Average B10 Depletion (%) | | Limiting Absorber Tube B10 Depletion (%) | |
|---|---|---|---|---|---|---|---|---|
| | Nominal | Limiting | Nominal | Limiting | Nominal | Limiting | Nominal | Limiting |
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| Average | | | | | | | | ]] |

**Table 5.3 Marathon Upper Tolerance Diameter: Axial Percent B10 Depletion Profiles for 10% Worth Reduction**

| Axial Node | Normalized B10 Depletion Profiles | | Quarter Average B10 Depletion (%) | | Blade Average B10 Depletion (%) | | Limiting Absorber Tube B10 Depletion (%) | |
|---|---|---|---|---|---|---|---|---|
| | Nominal | Limiting | Nominal | Limiting | Nominal | Limiting | Nominal | Limiting |
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| Average | | | | | | | | ]] |

# 6 Conclusions

The nuclear analyses for the final design of the Marathon blade, which is the original equipment for the ESBWR, estimated the EOL lifetime [[ ]] snvt depending on the tube diameter with the EOL fluence at nominal tube dimensions being [[ ]]. The average heat generation ranged from [[ ]] W/g of $B_4C$ at the lower tolerance to [[ ]] W/g of $B_4C$ at the upper limit with a nominal value of [[ ]] W/g of $B_4C$. The depletion fraction for the limiting tube for a nominal axial blade burnup profile ranged from [[ ]] B10 depletion with a nominal value of [[ ]]. For the limiting axial profile, the depletion ranged from [[ ]] B10 depletion with a nominal value of [[ ]]

# 7 References


1. NEDE-31758P-A, "GE Marathon Control Rod Assembly," October 1991.
2. NEDE-30931-7-P Revision 7, "GE BWR Control Rod Lifetime," November 2004.
3. MCNP01A: General Electric version of Los Alamos National Laboratory code, MCNP – General Monte Carlo N-Particle Transport Code, DRF J11-02538, March, 1995.
4. MCNP4A - A General Monte Carlo N-particle Radiation Transport Code, Version 4A, LA-12625, March 1994.
5. R. Kinsey, Ed., "ENDF/B Summary Documentation," BNL-NCS-17541 (ENDF-201), 3rd ed. (ENDF/B-V), Brookhaven National Laboratory (1979, several revisions)
6. S. Sitaraman, "MCNP: Light Water Reactor Critical Benchmarks," NEDO-32028, General Electric Nuclear Energy (1992).
7. S. Sitaraman and F. Rahnema, "Criticality Analysis of Heterogeneous Light Water Reactor Configurations", Nuclear Science and Engineering, 113, March 1993.

# ENCLOSURE 3

# MFN 06-120

## Affidavit

## General Electric Company

## AFFIDAVIT

**I, George B. Stramback,** state as follows:

(1) I am Manager, Regulatory Services, General Electric Company ("GE") and have been delegated the function of reviewing the information described in paragraph (2) which is sought to be withheld, and have been authorized to apply for its withholding.

(2) The information sought to be withheld is contained in the GE proprietary report, NEDE-33243P, *ESBWR Marathon Control Rod Nuclear Design Report*, Class III (GE Proprietary Information), May 2006. GE proprietary information is identified by a dark red font with double underlines inside double square brackets. Figures and large equation objects are identified with double square brackets before and after the object. In each case, the superscript notation {3} refers to Paragraph (3) of this affidavit, which provides the basis for the proprietary determination.

(3) In making this application for withholding of proprietary information of which it is the owner, GE relies upon the exemption from disclosure set forth in the Freedom of Information Act ("FOIA"), 5 USC Sec. 552(b)(4), and the Trade Secrets Act, 18 USC Sec. 1905, and NRC regulations 10 CFR 9.17(a)(4), and 2.790(a)(4) for "trade secrets" (Exemption 4). The material for which exemption from disclosure is here sought also qualify under the narrower definition of "trade secret", within the meanings assigned to those terms for purposes of FOIA Exemption 4 in, respectively, Critical Mass Energy Project v. Nuclear Regulatory Commission, 975F2d871 (DC Cir. 1992), and Public Citizen Health Research Group v. FDA, 704F2d1280 (DC Cir. 1983).

(4) Some examples of categories of information which fit into the definition of proprietary information are:

a. Information that discloses a process, method, or apparatus, including supporting data and analyses, where prevention of its use by General Electric's competitors without license from General Electric constitutes a competitive economic advantage over other companies;

b. Information which, if used by a competitor, would reduce his expenditure of resources or improve his competitive position in the design, manufacture, shipment, installation, assurance of quality, or licensing of a similar product;

c. Information which reveals aspects of past, present, or future General Electric customer-funded development plans and programs, resulting in potential products to General Electric;

d. Information which discloses patentable subject matter for which it may be desirable to obtain patent protection.

The information sought to be withheld is considered to be proprietary for the reasons set forth in paragraphs (4)a., and (4)b, above.

(5) To address 10 CFR 2.390 (b) (4), the information sought to be withheld is being submitted to NRC in confidence. The information is of a sort customarily held in confidence by GE, and is in fact so held. The information sought to be withheld has, to the best of my knowledge and belief, consistently been held in confidence by GE, no public disclosure has been made, and it is not available in public sources. All disclosures to third parties including any required transmittals to NRC, have been made, or must be made, pursuant to regulatory provisions or proprietary agreements which provide for maintenance of the information in confidence. Its initial designation as proprietary information, and the subsequent steps taken to prevent its unauthorized disclosure, are as set forth in paragraphs (6) and (7) following.

(6) Initial approval of proprietary treatment of a document is made by the manager of the originating component, the person most likely to be acquainted with the value and sensitivity of the information in relation to industry knowledge. Access to such documents within GE is limited on a "need to know" basis.

(7) The procedure for approval of external release of such a document typically requires review by the staff manager, project manager, principal scientist or other equivalent authority, by the manager of the cognizant marketing function (or his delegate), and by the Legal Operation, for technical content, competitive effect, and determination of the accuracy of the proprietary designation. Disclosures outside GE are limited to regulatory bodies, customers, and potential customers, and their agents, suppliers, and licensees, and others with a legitimate need for the information, and then only in accordance with appropriate regulatory provisions or proprietary agreements.

(8) The information identified in paragraph (2), above, is classified as proprietary because it contains detailed ESBWR design information and dimensional information regarding the Marathon Control Rod developed by GE over a period of several years at a cost of over one million dollars.

The development of the testing and evaluation process along with the interpretation and application of the analytical results is derived from the extensive experience database that constitutes a major GE asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GE's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GE's comprehensive BWR safety and technology base, and its commercial value extends beyond the original development cost. The value of the technology base goes

beyond the extensive physical database and analytical methodology and includes development of the expertise to determine and apply the appropriate evaluation process. In addition, the technology base includes the value derived from providing analyses done with NRC-approved methods.

The research, development, engineering, analytical and NRC review costs comprise a substantial investment of time and money by GE.

The precise value of the expertise to devise an evaluation process and apply the correct analytical methodology is difficult to quantify, but it clearly is substantial.

GE's competitive advantage will be lost if its competitors are able to use the results of the GE experience to normalize or verify their own process or if they are able to claim an equivalent understanding by demonstrating that they can arrive at the same or similar conclusions.

The value of this information to GE would be lost if the information were disclosed to the public. Making such information available to competitors without their having been required to undertake a similar expenditure of resources would unfairly provide competitors with a windfall, and deprive GE of the opportunity to exercise its competitive advantage to seek an adequate return on its large investment in developing these very valuable analytical tools.

I declare under penalty of perjury that the foregoing affidavit and the matters stated therein are true and correct to the best of my knowledge, information, and belief.

Executed on this 5th day of May 2006

George B. Stramback
General Electric Company