Enclosure 2

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GEH Nuclear Energy, "Gamma Thermometer System for LPRM Calibration and Power Shape Monitoring," NEDO-33197, Revision 2, August 2008 – Non-Proprietary Version

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Licensing Topical Report

Gamma Thermometer System for LPRM Calibration and Power Shape Monitoring

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ABSTRACT

A Gamma Thermometer (GT) System for LPRM calibration and power shape monitoring is described. The major hardware and software components are identified and a practical GT response model is developed. Three in-plant tests at Limerick 2 (Exelon), Tokai 2 (JAPC) and Kashiwazaki-Kariwa 5 are provided to qualify the sensors and assess accuracy. An adaptive core monitoring simulation is used to assess the impact of the GT System on core monitoring. Lastly, an uncertainty analysis is performed to quantify the impact on bundle power uncertainty and on thermal limits uncertainties.

ACRONYMS AND ABBREVIATIONS

Term	**Definition**
BOC	Beginning of cycle
BWR	Boiling Water Reactor
CFR	Code of Federal Regulations
CMS	Core Monitoring System
CPR	Critical Power Ratio
DACS	Data Acquisition and Calibration System
DAS	Data Acquisition System
DLC	Data Logging Computer
EOC	End Of Cycle
EWS	Engineering Work-Station
ESBWR	Economic Simplified Boiling Water Reactor
FS	Full Scale
GETAB	General Electric Thermal Analysis Basis
GT	Gamma Thermometer
GTC	Gamma Thermometer Control Unit
GTM	Gamma Thermometer Monitoring Unit
HPS	Heater Power Supply
HSU	Heater Switching Unit
LPRM	Local Power Range Monitor
LTR	Licensing Topical Report
MCPR	Minimum Critical Power Ratio
MLHGR	Maximum Linear Heat Generation Rate
NA	Not Applicable
NRC	Nuclear Regulatory Commission
O&M	Operation and Maintenance
PANAC11	PANACEA, GEH BWR Core Simulator
TIP	Traversing In-core Probe

1. INTRODUCTION

A GT is a simple device for measuring the thermal effects of intense gamma ray fields. GTs show great promise in simplifying BWR in-core instrumentation for nuclear plants by providing an economical alternative to the Traversing In-core Probe (TIP) system.

The TIP system, which may be based on either gamma or neutron sensitive detectors, provides measurements for (1) calibrating the Local Power Range Monitors (LPRMs) and (2) to adapt (improve) the power distribution for CMS used for calculating thermal parameters. Although TIP systems fulfill the intended purpose quite satisfactorily, the Operating and Maintenance (O&M) costs are high. This is primarily due to the many moving parts in the system, the complex under-vessel tubing which must often be disconnected during maintenance, and the radiation dose to maintenance personnel in the area of the stored TIP probes. A GT system, on the other hand, fulfills the functions of the TIP system, yet it has no moving parts, no under vessel tubing, virtually no radiation dose to maintenance since it is a fixed in-core probe, and is expected to be very reliable. However, as shown in Chapter 9, slightly larger uncertainties in monitoring LGHR margins are incurred as the number of measured axial locations is reduced.

A Gamma Thermometer based instrument system has been selected in place of a TIP system for the Economic Simplified Boiling Water Reactor (ESBWR) and is likely to be incorporated in future BWR designs and possibly retrofitted in existing plants.

1.1 Purpose

The purpose of this document is to supply regulators (and others) with sufficient information to understand the technical features of the GT system and to confirm the suitability of the GT system for LPRM calibration and power distribution monitoring.

1.2 Scope of Review

GEH requests that the NRC approve the GT system for calibration of LPRMs and for supplying power shape information to the core monitoring system.

1.3 Description of a Gamma Thermometer

A GT is a device used for measuring the gamma flux in a nuclear reactor. A section of a typical GT string and a GT sensor is shown in Figure 1-1. It consists of a stainless steel rod that has short sections of its length thermally insulated from the reactor coolant that flows within the LPRM/GT assembly. The insulation, normally a chamber of Argon gas, allows the temperature to rise in the insulated section in response to gamma energy deposition. A two-junction thermocouple measures the temperature difference between the insulated and non-insulated sections of the rod as shown in Figure 1-2. The thermocouple reading is thus related in a straightforward way to the gamma flux. When properly adjusted for the number and spectrum of the gamma rays produced from fission and neutron capture, the fission density in the surrounding fuel can be inferred from the gamma flux and therefore indirectly from the thermocouple reading.

An ohmic heater wire is placed in the center of the GT rod to provide a means of calibrating the thermometers, which are expected to decline slowly in sensitivity during the first few months of operation. The calibration procedure consists of passing a known current through the heater wire and noting the increase in the sensor response. When properly calibrated in this manner, the GT can perform both of the normal functions of a TIP: calibration of the LPRMs and providing power shape information to the plant monitoring system.

A diagram of a LPRM/GT assembly that is designed to replace a standard LPRM/TIP assembly is shown in Figure 1-3. The LPRM/GT assembly consists of a GT rod with multiple GT sensors and the normal compliment of four LPRMs.

1.3.1 GT Material Details

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Figure 1-1, Cross Section of a Typical Gamma Thermometer (dimensions are typical)

Note: Units are in inches.

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Figure 1-2, Heat Flow Path of GT

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Fiure 1-3, Typical LPRM/GT Assembly

1.4 Advantages of the GT System

The GT System has many advantages over the TIP system:

- No moving parts to wear out
- Reduced occupation exposure
- Reduced radioactive waste
- No open tube penetrations to the containment
- Reduced space requirements in the reactor building
- More frequent LPRM calibrations
- More frequent adaptive monitoring calculations

2. GT SYSTEM REQUIREMENTS

2.1 Design Requirements

There are two general functional requirements for the GT system:

- Provide accurate information for the calibration of the LPRMs. Such calibration must occur as determined by individual plant technical specifications, although it may occur much more frequently, even multiple times in a single day, utilizing the GT system. This function is only performed during steady state core conditions.
- Provide axial shape information for use by the core monitoring system. This information is only utilized during steady state core conditions.

2.2 Codes and Standards

LPRM/GT assemblies must be designed, manufactured and tested according to all applicable U.S. Codes and Standards.

When manufactured for use in a nation other than the U.S., LPRM/GT assemblies must also comply with that nation's codes and standards.

3. GT SYSTEM DEFINITION

3.1 Typical Hardware Components

The hardware configuration for a typical GT core monitoring system is shown in Figure 3-1. The hardware includes new components such as the LPRM/GT assemblies, a control cabinet, the Data Acquisition System (DAS) and the Heater Power Supplies (HPS). A listing of the new components is provided in Table 3-1. Also listed is the number of each type of component that is required for a typical system.

Table 3-1, GT Core Monitoring Component List

Component Name	Number (*Typical*)
LPRM/GT Assemblies	64
GT Sensors per Assembly	7
Data Acquisition System Cabinets	2
Heater Power Supplies	16
GT Control Cabinet (including Work-Station)	1

3.1.1 LPRM/GT Assembly

A typical LPRM/GT assembly is shown in Figure 1-3. The LPRM/GT assemblies are similar to standard LPRM assemblies: each has four LPRMs and is designed to meet all of the normal requirements. In the ESBWR configuration, each assembly has one GT string with seven GT sensors. One GT sensor is positioned adjacent to each LPRM and one midway between each pair of LPRMs. In alternate designs nine GT sensors are used and positioned as follows: one adjacent to each LPRM, one midway between each pair of LPRMs, one midway between the bottom of the core and the lowest LPRM and finally, one midway between the highest LPRM and the top of the core. With the four GT sensor configuration, a GT sensor is positioned adjacent to each LPRM.

The environmental design ratings, including the operating temperature, neutron flux, gamma dose rate and seismic loadings are the same as the standard LPRM assemblies. The GT sensors are designed to last at least as long as the LPRMs.

For demonstration systems only, a calibration tube is included in the assembly so that the TIP system remains operational. This permits a direct comparison between the TIP and GT systems.

3.1.2 Data Acquisition System

The main function of the DAS is to transform the GT readings from an analog signal to a digital value. The environmental design ratings are similar to other electronics in the reactor building. In addition, the DAS system may perform digital filtration to remove noise.

3.1.3 Heater Power Supply

The purpose of the HPS is to provide a DC electrical current to the internal GT heaters during calibration. The current must be of sufficient magnitude to allow an accurate calibration of each GT sensor. The HPS, for economic reasons, may be multiplexed such that several GT assemblies are serviced sequentially by a single power supply. In Figure 3-1, the HPS is included in the DAS cabinets.

3.1.4 GT Control Cabinet

The GT Control Cabinet contains an Engineering Work-Station (EWS) that is the principal interface to the GT system. The EWS communicates with the other units including the DAS, ATLM, & 3D MONICORE^{TM} cabinets through the plants communications system.

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Figure 3-1, Typical GT Core Monitoring System Configuration

3.2 Typical Software Components

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3.2.1 GT Monitor Module

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3.2.2 GT Calibration Module

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3.2.3 3D Simulator

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3.2.4 User Interface

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Figure 3-2, Typical GT Core Monitoring Software Diagram

4. GT RESPONSE MODEL

4.1 GT Response to Gamma Energy Deposition

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4.2 GT Factory Calibration

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4.3 GT In-Plant Calibration

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4.4 Void Fraction Response and Bypass Subcooling

4.4.1 Void Fraction Response

Voiding is not expected to occur within the LPRM/GT assembly during normal operating conditions. However, an analysis was performed to address the sensitivity of the GT response to voiding. The GT detects gamma rays from different energy spectra, and the total gamma cross section generally increases exponentially by atomic numbers. The gamma attenuation effect is less sensitive to the bypass void. In order to confirm this effect, the energy deposition into the GT sensors is compared to two different bypass void conditions in the gamma transport calculation of Monte Carlo nuclear code. A typical GE14E lattice is selected where the level-D LPRM located assuming the maximum [[ ]] bypass void with [[ ]] in-channel instantaneous void under a [[ ]] void history. This condition is consistent with the feedwater temperature/power operating domain for ESBWR. The other compared case has no bypass void with the same in-channel void condition above. The comparison includes the effect of different gamma source distributions due to different bypass void conditions. The relative difference of the energy deposition in GT sensors is [[ ]].

Another investigation of GT sensitivity to voids in the instrument tube is documented in the literature [5]. As described in this reference, Toshiba has performed thermo-hydraulic testing on an experimental GT assembly using the Multiple-Use Safety Experimental (MUSE) Facility. The MUSE facility can simulate BWR core conditions of saturation temperature, saturation pressure, and void fraction. The test objective was to confirm the GT sensitivity to changes in fluid conditions. In the test, an inlet heater was used to produce voiding in the test piece. The test piece was manufactured to the same specifications as the in-plant test specimen except for the length. Figure 4-1 (extracted from Reference [5]) shows the relationship between heating power and GT output signal. Even for the highest void fraction of 55% achieved in the tests, the change in the GT output signal is negligible for all the heating powers that were tested.

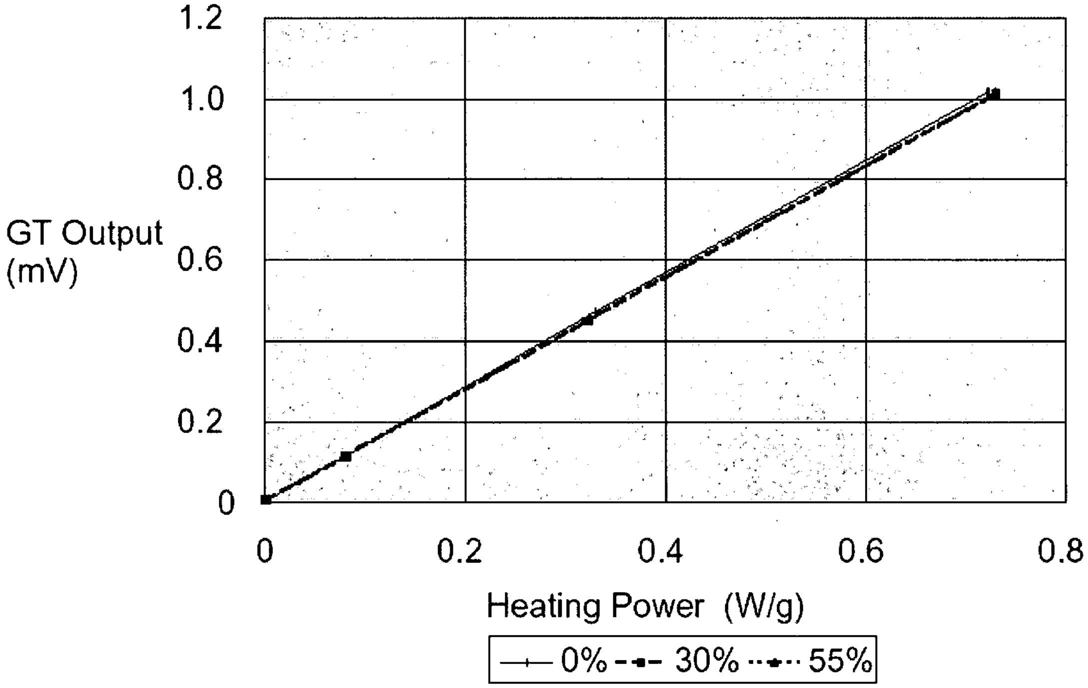

Figure 4-1, GT Output Signal vs. Heating Power Under Varying Void Fraction

* %Void Fraction

4.4.2 Bypass Subcooling

In addition to the utilization of control rods to control reactor power, the ESBWR will implement Feedwater Temperature control. However, prior to LPRM calibrations specific [[

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4.5 Delayed Gamma Compensation

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[*] Average thermal time constant (Joule method) of the detectors in the Joint Study

5. GT SYSTEM FUNCTIONS

The two functions of the GT System, LPRM calibration and power shape monitoring, are briefly described in the following sections.

5.1 LPRM Calibration

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5.2 Core Monitoring with GT Adaption

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6. FACTORY TESTS

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6.1 GT Factory Tests

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6.2 LPRM/GT Assembly Factory Tests

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7. IN-PLANT QUALIFICATION TESTS

There have been three in-plant tests of GT sensors in BWRs thus far. The first test was at Limerick 2 and lasted for two cycles, a total of four years. The second test, which was at Tokai 2, lasted for a single cycle of one year duration. These two tests will be described in detail in sections 7.1 and 7.2 , respectively. Published data from a third test at Kashiwazaki-Kariwa 5 are available in the open media and are summarized in section 7.3.

7.1 Limerick 2 In-Plant Test

The Limerick 2 plant, operated by Exelon (formerly PECO Energy) is an 1100 MWe BWR4. It has 764 bundles arranged in a "C" lattice configuration (equal water gaps). It has a gamma sensitive TIP system with a total of 43 calibration tubes and associated LPRM strings.

7.1.1 Test Plan

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Figure 7-1, Limerick 2 Core Map

7.1.2 Hardware Description

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Figure 7-2, Heater Current During GT Calibration

7.1.3 GT Calibration Results

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Figure 7-3, GT 1 Sensitivity

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Figure 7-4, GT 2 Sensitivity

7.1.4 Comparison with Gamma TIPs

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Table 7-1, Statistical Differences between GT and TIP Readings

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Figure 7-5, GT 1 vs. Gamma TIP

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Figure 7-6, GT 2 vs. Gamma TIP

7.1.5 Conclusions

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7.2 Tokai 2 In-Plant Test

The Tokai 2 plant, operated by Japan Atomic Power Company (JAPC), is an 1100 MWe BWR5 with 764 fuel bundles arranged in a C lattice. It has a neutron sensitive TIP system with a total of 43 calibration tubes.

7.2.1 Test Plan

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Figure 7-7, GT Rod

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Figure 7-8, Tokai 2 Core Map

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7.2.2 Hardware Description

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7.2.3 GT Calibration Results

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Figure 7-9, Fixed Alpha GT Sensitivity for RSTK-01

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Figure 7-10, Fixed Alpha GT Sensitivity for RSTK-02

7.2.4 Deleted

7.2.5 Steady State Response

7.2.5.1 Comparison with Neutron TIPs

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Table 7-2, Difference (%)[*] between GT[**] and TIP Readings for RSTK-01

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Table 7-3, Difference (%)* between GT** and TIP Readings for RSTK-02

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Table 7-4, Difference (rd)[*] between GT[**] and TIP Readings for RSTK-01

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Table 7-5, Difference (rd)* between GT** and TIP Readings for RSTK-02

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Table 7-6, Difference (rd)* between GT and TIP Four-Bundle Powers for RSTK-01

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Table 7-7, Difference (rd)* between GT and TIP Four-Bundle Powers for RSTK-02

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Table 7-8, Summary of RMS (rd)[*] Differences between GT[**] and TIP Four-Bundle Powers and Readings

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Figure 7-11, Comparison of GT with TIP Readings for RSTK-01

Figure 7-12, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-13, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-14, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-15, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-16, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-17, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-18, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-19, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-20, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-21, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-22, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-23, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-24, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-25, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-26, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-27, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-28, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-29, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-30, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-31, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-32, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-33, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-34, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-35, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-36, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-37, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-38, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-39, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-40, Comparison of GT with TIP Readings for RSTK-0

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Figure 7-41, Comparison of GT with TIP Readings for RSTK-0

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Figure 7-42, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-43, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-44, Comparison of GT with TIP Readings for RSTK-02

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Figure 7-45, Comparison of GT with TIP Readings for RSTK-01

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Figure 7-46, Comparison of GT with TIP Readings for RSTK-02

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7.2.5.2 Comparison with LPRMs

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Figure 7-47, Comparison of GT with LPRM Readings for RSTK-01 (steady-state)

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Figure 7-48, Comparison of GT with LPRM Readings for RSTK-02 (steady-state)

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7.2.6 Response During Non-Steady State Conditions

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7.2.6.1 Response During Startup

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Figure 7-49, Comparison of GT with LPRM Readings for RSTK-01 (startup)

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Figure 7-50, Comparison of GT with LPRM Readings for RSTK-02 (startup)

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7.2.6.2 Response to Flow Change

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Table 7-9, Comparison of Un-Compensated GT with LPRM Readings for RSTK-01 (flow change)

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Table 7-10, Comparison of Un-Compensated GT with LPRM Readings for RSTK-02 (flow change)

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Table 7-11, Comparison of Delayed Gamma Compensated GT with LPRM Readings for RSTK-01 (flow change)

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Table 7-12, Comparison of Delayed Gamma Compensated GT with LPRM Readings for RSTK-02 (flow change)

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Figure 7-51, Un-Compensated GT vs. LPRM Readings for RSTK-01 (flow change)

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Figure 7-52, Un-Compensated GT vs. LPRM Readings for RSTK-02 (flow change)

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Figure 7-53, Delayed Gamma Comp. GT vs. LPRM Readings for RSTK-01 (flow change)

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Figure 7-54, Delayed Gamma Comp. GT vs. LPRM Readings for RSTK-02 (flow change)

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7.2.6.3 Response to Control Rod Movement

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Table 7-13, Comparison of Un-Compensated GT with LPRM Readings for RSTK-01 (control blade pattern change)

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Table 7-14, Comparison of Un-Compensated GT with LPRM Readings for RSTK-02 (control blade pattern change)

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Table 7-15, Comparison of Delayed Gamma Compensated GT with LPRM Readings for RSTK-01 (control blade pattern change)

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Table 7-16, Comparison of Delayed Gamma Compensated GT with LPRM Readings for RSTK-02 (control blade pattern change)

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Figure 7-55, Un-Compensated GT vs. LPRM Readings for RSTK-01 (CB move)

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Figure 7-56, Un-Compensated GT vs. LPRM Readings for RSTK-02 (CB move)

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Figure 7-57, Delayed Gamma Comp. GT vs. LPRM Readings for RSTK-01 (CB move)

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Figure 7-58, Delayed Gamma Comp. GT vs. LPRM Readings for RSTK-02 (CB move)

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7.2.6.4 Response During Power Down

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Figure 7-59, Un-Compensated GT vs. LPRM Readings for RSTK-01 (power down)

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Figure 7-60, Un-Compensated GT vs. LPRM Readings for RSTK-02 (power down)

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Figure 7-61, Delayed Gamma Comp. GT vs. LPRM Readings for RSTK-01 (power down)

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Figure 7-62, Delayed Gamma Comp. GT vs. LPRM Readings for RSTK-02 (power down)

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Figure 7-63, Un-Compensated GT Linearity for Sensor 2 at RSTK-01 (power down)

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Figure 7-64, Delayed Gamma Comp. GT Linearity for Sensor 2 at RSTK-02 (power down)

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7.3 Kashiwazaki-Kariwa 5 In-Plant Test

The Kashiwazaki-Kariwa 5 plant is an 1100 MWe BWR5 operated by Tokyo Electric Power Company. The core has 764 bundles arranged in a "C" lattice configuration. The TIP system is neutron sensitive and has 43 calibration tubes and associated LPRM strings.

The research reported here was sponsored jointly by Tokyo Electric Power Company, Tohoku Electric Power Company, Chubu Electric Power Company, Hokuriku Electric Power Company, The Chugoku Electric Power Company, The Japan Atomic Power Company, Toshiba Corporation, Hitachi, Ltd. and Global Nuclear Fuel – Japan (see reference 4).

7.3.1 Test Plan

The test plan was to install 8 LPRM/GT assemblies with 9 GT sensors each (4 each from two separate suppliers) into an octant of the core. A comprehensive core monitoring study would therefore be possible, subject only to the condition of octant symmetry. Standard TIP calibration tubes were installed in the LPRM/GT assemblies so that normal TIP set measurements could be taken.

In order to assess the accuracy of core monitoring with GT readings, a bundle gamma scan was to be performed at the end of one cycle of operation. The scan was to include all of the bundles in the octant of the core as well as three additional bundles chosen so that all four bundles around each LPRM/GT assembly were included.

In addition, comparisons of core monitoring results between the GT and the neutron TIP systems were to be made throughout the cycle.

The LPRM/GT assemblies were to have nine sensors each, arranged in a manner similar to the Tokai 2 In-Plant test. The core locations for the assemblies are shown in Figure 7-65.

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Figure 7-65, Kashiwazaki-Kariwa 5 Core Map

7.3.2 Test Results

The gamma scan measured the strong photo peak of ^{140}La the short-lived daughter of the common fission product ^{140}Ba. Measurements were taken at 17 axial locations, generally every six inches, but excluding nodes obscured by spacers and excluding the top and bottom nodes. The ^{140}Ba distribution was calculated by an off-line core monitoring system throughout the cycle on a time interval of every 3 days. TIP adaptive core monitoring calculations were made 36 times during the cycle for the standard simulation. An equal number of GT adaptive calculations were made for the GT core monitoring simulation. Data were available only for seven of the eight GT assemblies[2], but this did not significantly detract from the results of the study.

The results showed very good agreement between the calculated and measured ^{140}Ba distributions for both the GT adaptive monitoring and the TIP adaptive monitoring. Table 7-17 shows the RMS differences between the calculated and measured distributions as measured for the 1D (axial) distribution, for the 2D (bundle) radial distribution and for the 3D (nodal) distribution.

Table 7-17, RMS Differences between Calculated and Measured ^{140}Ba Distributions

Distribution	n TIP vs. γ Scan	GT vs. γ Scan
1D (axial)	1.7%	2.1%
2D (bundle)	2.5%	2.3%
3D (nodal)	3.9%	4.1%

In addition to the gamma scan studies, comparisons were also made between the thermal limits calculated by the two core monitors. The RMS difference for the whole cycle between the MCPR calculated by the GT core monitor and the MCPR calculated by the neutron TIP monitor was 0.008. The maximum difference was 0.02.

Similarly, the RMS difference between the MLHGR calculated by the GT core monitor and the MLHGR calculated by the neutron TIP was 0.4 KW/m and the maximum difference was 1 KW/m.

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[2] According to a personal communication, one of the assemblies planned for the test experienced a failure that affected all nine sensors in the assembly. Modern core monitors such as 3DMonicore are tolerant of this type of fault and are able to produce accurate results with several assemblies out of service.

7.3.3 Conclusions

The comparison with the gamma scan established that core monitoring based on GTs is nearly equivalent in accuracy to core monitoring with neutron TIPs. In addition, it was shown that the thermal limits, MCPR and MLHGR, evaluated by the two core monitoring systems were very similar throughout the cycle.

The overall conclusion was that the GT system is "practical as a substitute" for the TIP system.

8. ADAPTIVE CORE MONITORING SIMULATION

One of the most important functions of the GT system is to provide information to the Core Monitoring System for power shape monitoring and thermal margin determination. Most modern CMSs, such as 3D MONICORE™, [[

]] The uncertainty analysis is addressed in Chapter 9.

8.1 The TIP-based Monitoring System Functions

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8.2 The Difference of the GT-based Monitoring System

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8.3 Simulated GT Readings Study

In order to analyze the GT system performance as a core monitoring system, a study was carried out using core-wide simulated GT readings to adapt PANAC11 calculated power shapes of two BWRs where measured TIP data was collected (and selected as reference). The results are used as the basis for discussion of GT-related uncertainties in the framework of Reference 3 (SLMCPR licensing topical report). This study addresses expected ESBWR conditions, namely, the [[

]].

A modified version of [[ ]] for the GT system was created and tested to determine the GT-associated uncertainties that are described in Chapter 9. During the process, superseding information was generated that updates the responses to NRC RAI 4.2-12 S02 parts 10 and 11 as explained in the response to NRC RAI 7.2-18 S02 (both responses presented in Appendix A).

In the following subsection, the description of the reactor cores, the GT adaption technique and the description of the boundary conditions used in this study are presented.

8.3.1 Description of the Reactor Cores

The reactors selected have a power density greater than [[ ]]. One of the selected reactors is a [[ ]] and has [[ ]] and is referred to as Plant E. BOC, MOC and EOC calculated power distributions were obtained with [[ ]] and compared to measured power distributions [[ ]]. The second reactor selected is a [[ ]] referred to as [[ ]]. Its calculated power distribution was compared to the measured power distribution [[ ]] was used as the [[ ]] for both reactor power distributions. The GT readings were assumed as equal to the corresponding TIP reading (either thermal-TIP or gamma-TIP) at the GT sensor locations for the core-wide simulations.

8.3.2 GT Adaption Methodology

The selected GT-adaption method for the ESBWR monitoring system [[

]]

[[ ]][1]

[[ ]]

---

[1] [[ ]]

[[

]]

[[

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]]

[[

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[[

.

]]

8.3.3 Definition of Boundary Conditions

[[

]]

8.3.4 Additional Noise Component

[[

]]

8.3.5 GT Adaption Remarks

The implementation of the GT signals into PANAC11 adaptive process and the numerical examples studied in two reactors resulted in the following remarks:

- By virtue of the shape adaption, the radial uncertainty is [[
  ]].
  Core average exposure [[
-
  ]]

8.4 Detector Response

[[

C_{Gd_i}

]]

8.5 Detection of Anomalies and Signal Perturbations

The ramification of having an anomaly in one axial node that perturbs the power distribution locally can be described in terms of the information handled by the power monitoring system and for the actions that can be taken in-situ or previously to the core loading.

In case of unforeseen anomalies, [[

-

]]

Among potential perturbations that could occur in normal reactor operation and produce a signal bias, [[

]]

Consider that the ESBWR GT is located in the region between four fuel assemblies in the corner opposite from the control blade location. The spacer material [[

]]

[[

]]

9. UNCERTAINTY ANALYSIS

[[

]]

9.1 GT Sensor Accuracy

The ESBWR GT sensor is [[

]]

Table 9-1, SRS Requirements (Specific for the Tokai 2 Plant Test)

[[				
				]]

[[

]]

Table 9-2, GT Sensor Accuracy Criteria

[[				
				]]

9.2 GT Calibration Accuracy

[[

---

[4] [[

]]

]]

Table 9-3. Evaluation of GT Calibration Accuracy based on Tokai-2 Plant Test

[[					
					]]

9.3 GT Adaptive Core Monitoring Accuracy

The power uncertainties associated to the GT-based monitoring system are analyzed in the following sections. The uncertainty components correspond to the list of uncertainties described in Reference 3. The analyses are based on simulated GT readings and the purpose is to establish the uncertainties applicable to the MCPR and LHGR calculations for the ESBWR. At the end of the Chapter, the list of LHGR uncertainties is presented. Note that there are some uncertainties that are not related to the GT-based monitoring system but they are presented for completeness.

[[

]]

[[ ]]

A specific analysis was performed to establish the uncertainties caused by the LPRM calibration update and potential failure of GT instruments for the calculation of the Critical Power Ratio (CPR) and Linear Hear Generation Rate (LHGR). The analysis uses [[ ]]

The study relies [[ ]] to simulate GT sensor signals. Plant M, [[ ]]

The update uncertainty for the LPRM calibration is studied in a core-average exposure interval of [[ ]]

This plant is monitored with [[ ]]

[[ ]] for the current BWR fleet (NEDC-32694P-A, Reference 3). It is expected that [[ ]]

[[ ]]

9.3.1 MCPR Uncertainty

The following subsections present the applicable ESBWR uncertainties of the MCPR calculation.

9.3.1.1 Four Bundle Power Uncertainty

[[

]]

9.3.1.2 Power Allocation Uncertainty

[[

]]

9.3.1.3 LPRM Calibration Update Uncertainty

Figure 9-1 presents [[

]]

[[ ]]

[[

]]

[[

]]

[[ ]]

[[

]]

9.3.1.4 MCPR GT Failure Uncertainty

To determine the new instrument failure uncertainty for ESBWR with GT sensors, [[

c)]]

The study of the resulting monitoring configurations is based on a [[

]]

9.3.1.5 Total MCPR Update/Failure Uncertainty

For the GT application, the total update/failure uncertainty for the MCPR calculation is given as [[

]]

To obtain the total update/failure uncertainty for the ESBWR-MCPR calculation, the following formula is applied (this assumes independence among the components and separation of the effects):

[[

]]

This is [[ ]] the value presented in NEDC-32694P-A (Reference 3) for the update/failure uncertainty (0.62%) for the TIP-based system [[ ]]. Table 9-5 presents a comparison of uncertainties for the current BWR fleet and for the ESBWR.

[[

]]

[[

]]

9.3.2 LHGR Uncertainty

The following subsections present the applicable ESBWR uncertainties of the LHGR calculation.

9.3.2.1 Interpolation Uncertainty

[[

]]

[[ ]]

[[

]]

[[

]]

9.3.2.2 Random Uncertainty

[[

]]

9.3.2.3 LHGR GT Update Uncertainty

Table 9-7 provides more detail on the [[

]]

It is worth to note that the performance of the update process for the GT-based LPRM calibration is very similar to the performance of the update process for the TIP-based LPRM adaption.

[[

]]

[[

]]

[[ ]]

[[

]]

9.3.2.4 LHGR GT Failure Uncertainty

[[

]]

9.3.2.5 Summary of Uncertainties for LHGR Calculation

A [[ ]] is applied in the development of the LHGR limit. As shown in the Table 9-8, [[ ]] (from [[ ]] to [[ ]]) and the [[ ]] (from [[ ]]) results in total power distribution uncertainty [[ ]] that is currently applied to the development of the LHGR limit for equilibrium core loadings. Note that the gradient effect's uncertainty decreased from [[ ]] based on [[ ]].

Table 9-8 collects [[

]]

The following [[

4.

]]

9.3.3 Minimum Monitoring Configuration

[[

3.

]]

If those conditions are met, the total update/failure uncertainty for the MCPR and LHGR calculations will [[
]]

[[ ]]

[[

]]

10. CONCLUSIONS

The Gamma Thermometer System has been successfully evaluated as a replacement for the TIP system by a comprehensive In-Plant Test Program. The primary objectives of the Test Program have been met:

1. GT sensor accuracy relative to gamma TIP, neutron TIP and LPRM measurements has been evaluated; and

2. GT sensor reliability under BWR operating conditions has been established.

The GT sensitivity trends have been followed throughout a total of three cycles of operation at two BWRs. The sensitivity trend in the most recent test consisted of a relatively rapid initial rise during the first 500 hours of operation, followed by a slow decline for the rest of the cycle. However, in-plant calibrations provide the ability to adjust for any sensitivity changes.

The GT response in the steady state has been compared with gamma TIP and neutron TIP response as well as the LPRM response. The GT response during changing conditions (startup, flow change, control blade change and power down) has been compared with the LPRM response. The GT sensors were evaluated for accuracy with a combination of factory, in-plant and core monitoring tests:

1. For the Tokia 2 test the factory tests proved that the GT sensors met all of the requirements of the SRS.

2. The in-plant tests proved the accuracy, linearity and range of the GT sensors with respect to the TIPs and LPRMs.

3. Chapters 8 and 9 present the conclusions of the power uncertainty analysis for the GT-based monitoring system in its implementation to the ESBWR for LPRM calibration and power adaption in the framework of the SLMCPR and LHGR methodology approved in NEDC-32694P-A (Reference 3). The development of this work is presented in Appendix A.

The overall conclusion of the GT in-plant test program is:

The GT system can be used in place of a TIP system for both LPRM calibration and power shape monitoring.

11. REFERENCES

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2. F. Loisy, M. Huver, M. Janvier: "Technology and Use of Gamma Thermometers," Specialist Meeting on In-Core Instrument Proceedings, France, June 1988.

3. "Power Distribution Uncertainties for Safety Limit MCPR Evaluations," NEDC-32694P-A, August 1999.

4. H. Shiraga, et al., "Verification of Core Monitoring System with Gamma Thermometer," International Conference on Global Environment and Advanced Nuclear Power Plants, GENES4/ANP2003, Sep. 15-19, 2003, Kyoto, Japan.

5. R. Raghavan, et al., "Application of the Gamma Thermometer as BWR Fixed In-core Calibration System", 4th Specialists' Meeting on In-core Instrumentation and Reactor Core Assessment, 1996

6. MFN 08-293, "Response to Portion of NRC Request for Additional Information Letter NO.1 06 - Related to ESBWR Design Certification Application - RAI Numbers 4.2-12 Supplement 2 and 4.3-2 Supplement 2", April 2008.

7. MFN 07-613 Supplement 1, "Response to Portion of NRC Request for Additional Information Letter No. 137 Related to ESBWR Design Certification Application - RAI Number 7.2-59 Supplement 2", July 2008.

8. "Applicability of GE Methods to Expanded Operating Domains," NEDC-33173P, February 2006.

9. "GE14 for ESBWR Nuclear Design Report," NEDC 33239, April 2007.

10. "Methodology and Uncertainty for Safety Limit MCPR Evaluations," NEDC-32601P, December 1996.

APPENDIX A

The following NRC RAIs and GEH responses are included to provide additional information for the material presented in Chapters 8 and 9.

NRC RAI 7.2-18 S02

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NRC RAI 4.2-12 S02 PART 10

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NRC RAI 4.2-12 S02 PART 11

APPENDIX A

APPENDIX A

APPENDIX A

MFN 08-640

Enclosure 3

Affidavit

GE-Hitachi Nuclear Energy Americas LLC

AFFIDAVIT

I, **David H. Hinds**, state as follows:

(1) I am the General Manager, New Units Engineering, GE Hitachi Nuclear Energy ("GEH") 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 Enclosure 1 of GEH letter MFN 08-640, Mr. Richard E. Kingston to U.S. Nuclear Regulatory Commission, "Licensing Topical Report NEDE-33197P, Revision 2, Gamma Thermometer System for LPRM Calibration and Power Shape Monitoring," dated August 26, 2008. GEH Proprietary Information is identified in Enclosure 1, "GEH Nuclear Energy, "Gamma Thermometer System for LPRM Calibration and Power Shape Monitoring," NEDE-33197P, Revision 2, August 2008 – Proprietary Version," in dark red font and a dashed underline inside double square brackets. [[This sentence is an example.$^{\{3\}}$]] Figures, large equation objects, and some Tables 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 of the proprietary determination. Specific information that is not so marked is not GEH proprietary. A non-proprietary version of this information is provided in Enclosure 2, "GEH Nuclear Energy, "Gamma Thermometer System for LPRM Calibration and Power Shape Monitoring," NEDO-33197, Revision 2, August 2008 – Non-Proprietary Version."

(3) In making this application for withholding of proprietary information of which it is the owner, GEH 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 2.390(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 GEH's competitors without license from GEH 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 GEH customer-funded development plans and programs, resulting in potential products to GEH;
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 GEH, 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 GEH, 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, or subject to the terms under which it was licensed to GEH. Access to such documents within GEH 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 GEH 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 identifies the detailed GEH ESBWR methods, techniques, information, procedures, and assumptions related to its gamma thermometer system.

The development of the models and methodologies along with their application is derived from the extensive experience database that constitutes a major GEH asset.

(9) Public disclosure of the information sought to be withheld is likely to cause substantial harm to GEH's competitive position and foreclose or reduce the availability of profit-making opportunities. The information is part of GEH'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 GEH.

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.

GEH's competitive advantage will be lost if its competitors are able to use the results of the GEH 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 GEH 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 GEH 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 26th day of August 2008.

David H. Hinds
GE-Hitachi Nuclear Energy Americas LLC