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Subject: **Response to Portion of NRC Request for Additional Information Letter No. 85 - Decay Heat Analysis - RAI Number 6.3-62**

Enclosure 1 contains the GE-Hitachi Nuclear Energy Americas LLC (GEH) response to the subject NRC RAI transmitted via the Reference 1 letter.

If you have any questions or require additional information, please contact me.

Sincerely,

Kathy Sedney for

James C. Kinsey
Project Manager, ESBWR Licensing

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NRO

Reference:

1. MFN 07-054, Letter from U.S. Nuclear Regulatory Commission to David Hinds, *Request for Additional Information Letter No. 85 Related to ESBWR Design Certification Application*, January 19, 2007

Enclosure:

1. MFN 07-439 - Response to Portion of NRC Request for Additional Information Letter No. 85 - Related to ESBWR Design Certification Application - Decay Heat Analysis - RAI Number 6.3-62

cc:	AE Cubbage	USNRC (with enclosures)
	GB Stramback	GEH/San Jose (with enclosures)
	RE Brown	GEH/Wilmington (with enclosures)
	eDRF	0000-0062-0851

Enclosure 1

MFN 07-439

Response to Portion of NRC Request for

Additional Information Letter No. 85

Related to ESBWR Design Certification Application

Decay Heat Analysis

RAI Number 6.3-62

NRC RAI 6.3-62:

DCD Tier 2, Revision 2, Section 6.2.1.3 states that "Calculations of the energy available for release from the above sources are done in general accordance with the requirements of 10 CFR 50, Appendix K, paragraph I.A. However, additional conservatism is included to maximize the energy release to the containment during the blowdown and reflood phases of a LOCA." Please provide:

(A) A list of the conservative assumptions applied to the calculation of the decay heat for the ESBWR. Where applicable, quantify these conservative assumptions (e.g. if a reactor scram delay of 1 second is conservatively assumed, the additional heat load on the containment is given by the integrated reactor power over this interval). If an increase in core average exposure is applied to ensure conservatism in the decay heat, verify that the plutonium fission, and hence fractional decay heat contribution, was not artificially increased by providing the irradiation time and exposure assumptions for the analysis.

(B) A justification of the application of the same decay heat curve to both small and large break LOCAs. Particularly, provide an analysis demonstrating that the assumptions used to calculate the fission power during rod insertion and fission power from delayed neutrons are conservative for a full spectrum of LOCAs. If a TRACG analysis is used to demonstrate the conservatism, fully describe the calculation; including the specific decay heat option used, the initiator for the SCRAM signal, the evolution of the core average void fraction, and any assumptions regarding blade insertion time or axial load.

(C) A description of the heat sources considered in the decay heat analysis. If an evaluation of the decay heat model after ~100 seconds was performed to ensure that the ANS 1994 standard included sufficient conservatism to neglect the integrated effects of heat from other sources, describe the evaluation process and results. Otherwise, justify not including those sources.

(D) A description the distribution of the decay heat in the TRACG core model. Is the decay heat distribution based on the initial flux shape or the initial power shape?

(E) A comparison of the ESBWR specific design values for the hydraulic control unit valve deenergization and stroke time, instrument and logic delay time, and control blade insertion time to those values assumed in the calculation of the decay heat curve.

(F) An explanation of the reference to the 1979 ANS standard in DCD Tier 2, Revision 2, Table 6.3-11.

(G) A section in the next revision to the DCD that describes the assumptions in the shutdown power calculation that ensure that the power is conservative for a full spectrum of LOCAs for the ESBWR.

GEH Response:

(A) The ESBWR decay heat was generated based on ANSI/ANS-5.1-1994 standard with additional terms for a more complete shutdown power assessment. The heat sources considered include decay heat from fission products, actinides and activation products, as well as fission power from delayed and prompt neutrons immediately after shutdown. The effect of neutron capture in fission products is considered. The following assumptions are considered in the ESBWR core decay heat assessment:

1. The equilibrium core is treated as a single, averaged batch.
2. The fuel type assumed is GE14E.
3. Continuous irradiation at constant power for 3.8 years prior to shutdown.
4. The end-of-cycle core average exposure is 32 GWd/ST (35.3 GWd/MT).
5. The shutdown mode assumed in the ESBWR decay heat is consistent with a design-basis large break loss-of-coolant accident (LOCA).

Conventionally a higher exposure means a higher fractional fission in plutonium relative to ^{235}U, hence less decay heat. Nonetheless, the sensitivity of decay heat to exposure is not as prominent as that due to the irradiation time. A longer irradiation means more fissions and captures in the fuel, which leads to higher decay heat from fission products and actinides. In addition, more decay heat is produced as a result of increased neutron capture in fission products. The ESBWR decay heat was calculated based on end-of-cycle (EOC) exposure of 32 GWd/ST, which is approximately 5% higher than the equilibrium core average exposure. The irradiation time of 3.8 years is approximately 8% higher than the average batch in the equilibrium cycle.

(B) The total power comparison between the main steam isolation valve (MSIV) closure transient at EOC and bottom drain line (BDL) small break LOCA events demonstrates that there is no detrimental impact from the use of the calculated decay heat for the ESBWR LOCA break spectrum analyses. This conclusion is based on the higher potential of the MSIV closure transient at EOC event to insert positive reactivity (higher total power) compared to the BDL small break LOCA event. The potential for positive reactivity insertion is due to an expected lower void fraction from the MSIV closure transient at EOC pressurizing event. Therefore, if the total power from the BDL small break LOCA bounds the total power from the MSIV closure transient at EOC, the calculated decay heat used in the ESBWR LOCA spectrum is considered to be adequate and conservative. This is true because the main steam line (MSL) large break LOCA has an immediate negative void feedback greater than that of the BDL small break LOCA event, and the negative void feedback of the BDL small break LOCA is greater than that of the MSIV closure transient at EOC event.

Figure 6.3-62-1 (DCD Figure 6.2-8c) "Comparison of MSIV Closure Transient and BDL Break LOCA Decay Heat" shows that during both the early high energy gradient and later stages of these events, the decay heat power from the BDL small break LOCA (DCD Tier 2, Revision 3, Subsection 6.2.1.1.3.3) is higher than the one from the MSIV closure transient at EOC (DCD Tier 2, Revision 3, Subsection 15.2.2.7), except for a small time where the MSIV closure transient at EOC decay heat is (about 3%) above the nominal power for about 0.2 seconds (between 1 to 1.2 seconds into the event). Even though the decay heat from the MSIV closure transient at EOC event is slightly higher for a very short time, the contribution from this small peak to total power is shown to be negligible when compared to the time-integrated power for both events (as seen in Figure 6.3-62-2 and Figure 6.3-62-3). Furthermore, the pressure increase due to the MSIV closure transient at EOC and its positive reactivity insertion impact is neutralized by the negative reactivity from the control rod insertion. The impact on power from the negative void feedback during a BDL small break LOCA is greater than the one caused by the MSIV closure transient at EOC, because the transient event involves more limiting conditions that promote a smaller negative void feedback or none at all. Therefore, based on the behavior shown in the above comparison, it is demonstrated that the same decay heat values are applicable to the LOCA spectrum events identified in DCD Tier 2, Revision 3.

A scram delay time of 2.25 seconds is used in all of the TRACG ESBWR LOCA spectrum events. The overall decay heat impact of the TRACG ESBWR LOCA spectrum events as compared to the calculated decay heat assumptions is shown below in Item E as Table 6.3-62-1.

The following information is provided for both events:

1. For the MSIV closure transient at EOC event:
   - Decay Heat Option used: ICRTRG = 2, Control blades to move under TRIP02.
   - Initiator for scram signal: Scram signal by MSIV position at 85%, scram begins at 0.85 seconds.
   - Evolution of the Core average void fraction: See DCD Tier 2, Revision 3, Figure 15.2-9f.
   - Assumption regarding blade insertion: See DCD Tier 2, Revision 3, Table 15.2-3, the blade insertion times are based on a higher dome pressure (slower control blade insertion).
2. For the BDL small break LOCA event:
   - Decay Heat Option used: IRPOP = 3, Trip initiated table lookup of power.
   - Initiator for scram signal: Time (2.25 seconds after the break initiation at 0.00 seconds).
   - Evolution of the Core average void fraction: See Figure 6.3-62-4.
   - Assumption regarding blade insertion: See Item E below.

(C) The heat sources included in the ESBWR decay heat calculation include the following:

- Decay heat from fission products of ^{235}U, ^{239}Pu, ^{238}U, and ^{241}Pu.
- Decay heat from major actinides ^{239}U and ^{239}Np.
- Decay heat from miscellaneous actinides ^{237}U, ^{238}Np, ^{238}Pu, ^{241}Am, ^{242}Cm, ^{244}Cm, etc.
- Decay heat from activation products produced by neutron capture in fuel structural materials and fuel additives.
- Decay heat from isotopes produced by neutron capture in fission products.
- Fission power from delayed neutron induced fission.

The GEH decay heat calculation satisfies the ANSI/ANS-5.1--1994 standard and includes some improvements allowed by the standard. It considers the decay heat sources from fission products, actinides, and activation products, as well as fission power from delayed neutrons and decay heat associated with neutron capture effects. Details of the delayed neutron contribution are provided in the GEH response to RAI 6.3-61 (MFN 06-488 dated December 22, 2006). The neutron capture effect is accounted for with the G-factors specified in the ANS 1994 standard.

(D) The decay heat distribution used in the TRACG core model is based on initial power shape. See response to RAI 6.3-50 (MFN 07-282 dated May 17, 2007).

(E) The following parameters/delay times are assumed for a design-basis LOCA in the ESBWR decay heat assessment:

- 100 msec delay for the instrument to detect high drywell pressure.
- 600 msec delay from the high drywell pressure signal to de-energization of scram solenoid valve.
- Scram time delay from de-energization of scram solenoid valve to the start of rod motion (to overcome rod inertia) is 200 msec.

The combined scram delay following the accident is 900 msec (0.9 sec).

The decay heat modeling in DCD Tier 2, Chapter 6, LOCA events have an added delay time of 2.25 seconds. This delay time accounts for the following:

- 2.00 seconds loss-of-offsite power (LOOP) delay (time allowed to recover loss of feedwater pump power without scram).
- 0.050 seconds for Reactor Protection System (RPS) logic.
- 0.2 seconds scram time delay between loss of signal to scram solenoid air pilot valves and drop-out of the 0% reed switch (i.e., time between de-energization of scram solenoid valve to the start of rod motion to overcome rod inertia).

The design time period for the ESBWR instrument channel trip signal and the time when the scram pilot valve solenoids are de-energized (trip logic unit input to actuator operation) shall be less than 50 msec (0.05 seconds). Selected equipment will be specified to meet these time requirements under the environmental and radiological requirements for its location and for the intended operations.

The following Table 6.3-62-1 shows a comparison between the overall decay heat implementation on TRACG ESBWR LOCA spectrum events and the calculated decay heat assumptions.

Table 6.3-62-1

	ESBWR LOCA (seconds)		Decay Heat Assumptions (seconds)		Conservatism/Double Accounting (seconds)	
Instrument and Logic Delays	**Value**	**Explanation**	**Value**	**Explanation**	**Value**	**Explanation**
Time delay from event initiation to parameter at scram value	2.0	Time to confirm loss of power	0.1	Time for drywell pressure to reach scram setpoint	0.1	0.1 s added in Decay Heat calculated fission power, and 2 s delay already applied in TRACG (double accounting)
Sensor and RPS logic time delay	0.05	RPS delay	0.6	Drywell pressure Sensor and RPS delay	0.55	0.55 s added in Decay Heat calculated fission power, and 0.05 s delay already applied in TRACG (double accounting)
Time delay from de-energization of scram solenoid valves to start of rod motion	0.2	–	0.2	–	0.0	0.2 s added in Decay Heat calculated fission power, and 0.2 s delay already applied in TRACG (double accounting)
Time delay from start of rod motion to blade fully inserted	2.23	–	5.0	–	2.77	Slow insertion time relative to ESBWR control rods
Total	–	–	–	–	3.42	–

There is a total of 3.42 seconds of conservatism/double accounting in the fission power included in the decay heat table. Note that the conservatism in terms of heat addition, is less than 3.42 full-power seconds, because the fission power is reduced by void production in the LOCA case, and the difference in scram insertion time does not exactly correspond to fission power reduction, but this information is provided to explain the conservatisms shown on the integrated power plots.

The following control blade insertion time periods are provided for comparisons.

1. The design control blade insertion time periods for vessel bottom pressure below 7.481 Mpa gauge (1085 psig) are indicated below (DCD Tier 2, Revision 3, Table 15.2-2 and Table 4.6-2):

Rod Insertion %	Scram Time (seconds) (After De-energization (0.05 s)) Used in Analysis
0	0.0
Start of motion	≤ 0.20
10	≤ 0.34
40	≤ 0.80
60	≤ 1.15
100	≤ 2.23

2. The control blade insertion time periods assumed in the calculated decay heat used for the design basis LOCA in the ESBWR is given below for comparison (see Reference 2):

% Control Rod Insertion	Time After Accident (seconds)
0	0.9
5	1.075
20	1.600
50	2.700
90	5.700

(F) Reference to the 1979 ANS standard in DCD Tier 2, Revision 2, Table 6.3-11 was an editorial error. This editorial error was corrected in DCD Tier 2, Revision 3, Table 6.3-11. The reference for the Decay Heat, Nominal Value in Table 6.3-11, in DCD Tier 2, Revision 3, is stated as "1994 ANS (Figure 6.3-39)". Also see the response to RAI 6.3-61 (MFN 06-488 dated December 22, 2006).

(G) DCD Tier 2, Subsection 6.2.1.1.3 and Figure 6.2-8c (Figure 6.3-62-1 in this response) will be revised to describe the assumptions in the shutdown power and a demonstration that the decay heat power is conservative for a full ESBWR LOCA spectrum.

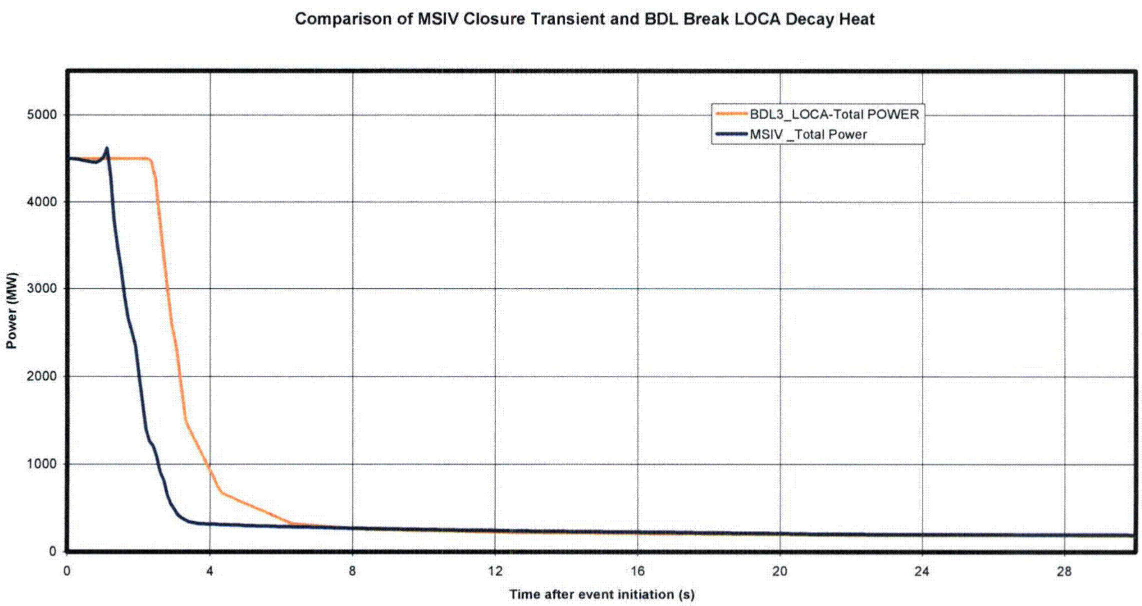

Figure 6.3-62-1 (DCD Tier 2, Figure 6.2-8c)

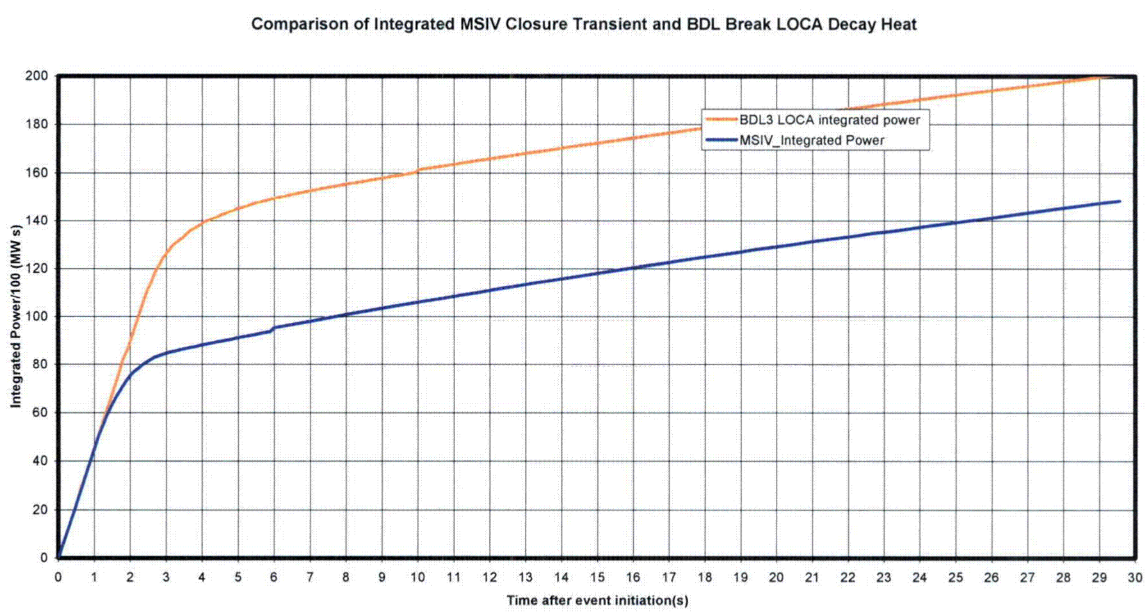

Figure 6.3-62-2

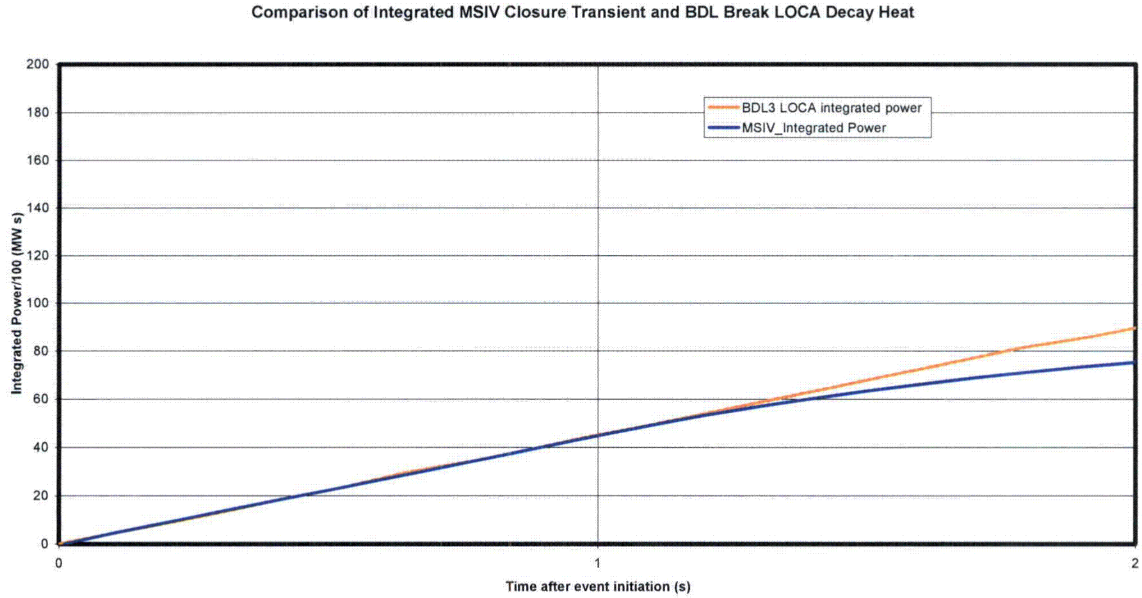

Figure 6.3-62-3

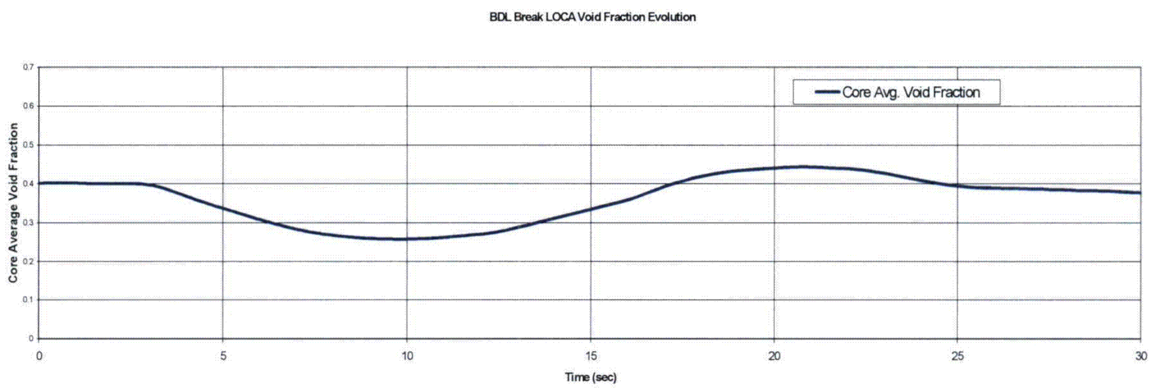

Figure 6.3-62-4

References:

1. J.G.M. Anderson at al., TRACG Model Description, NEDE-32176P, Revision 3, GE Licensing Topical Report, April 2006, Section 9.0 and Subsection 9.1.3.
2. G. J. Scatena and G. L. Upham, Power Generation in a BWR Following Normal Shutdown or Loss-Of-Coolant Accident Conditions, NEDO-10625, GE Licensing Topical Report, April 1973, Section 3.4.

DCD Impact:

DCD Tier 2, Figure 6.2-8c will be revised consistent with Figure 6.3-62-1 in this response. DCD Tier 2, Subsection 6.2.1.1.3 will be revised to add the text shown in the attached markup.

6.2.1.1.3 Design Evaluation

[To be added to this subsection]

ESBWR Core Decay Heat

The ESBWR core decay heat is generated based on the ANSI/ANS-5.1-1994 standard with additional terms to account for a more complete shutdown power assessment. The heat sources considered include decay heat from fission products, actinides and activation products; as well as fission power from delayed and prompt neutrons immediately after shutdown. The effect of neutron capture in fission products is considered. However, initial energy stored in the fuel assembly and heat from metal-water reaction during severe accident are not considered in the decay heat calculations.

The input parameters for the ESBWR decay heat calculation are derived based on the equilibrium core design. Additional safety margins are added to the core parameters in order to bound future cycle variations as well as other fuel product lines with similar parameters. The fuel type assumed in the ESBWR decay heat calculation is GE14E. A constant power irradiation for 3.8 years to reach end-of-cycle exposure of 32 GWd/ST is assumed prior to shutdown. The shutdown mode assumed in the ESBWR decay heat is consistent with a design-basis large break LOCA.

The decay heat modeling for the break LOCA events discussed in this chapter. including the listed fission power after shutdown or decay heat values is consistent, adequate and applicable to the entire LOCA break spectrum due to conservatisms included in its application (see Figure 6.2-8c). These values represent the core average decay heat at the end-of-cycle.