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Subject: **NEDO-33201, Revision 1, "ESBWR Probabilistic Risk Assessment," Section 17**

Enclosure 1 contains the subject partial ESBWR Probabilistic Risk Assessment (PRA) document (Revision 1).

If you have any questions about the information provided here, please let me know.

Sincerely,

Kathy Sedney for

David H. Hinds
Manager, ESBWR

D068

Enclosure:

1. MFN 06-250 – NEDO-33201, Revision 1, "ESBWR Probabilistic Risk Assessment:"
    - Section 17 – Results Summary

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	LA Dudes	USNRC (w/o enclosures)
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ENCLOSURE 1

MFN 06-250

NEDO-33201, Revision 1, "ESBWR Probabilistic Risk Assessment"

- **Section 17 – Results Summary**

17 RESULTS SUMMARY

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17 RESULTS SUMMARY

This section provides a summary of the various ESBWR PRA results that, in turn, can be used in comparison with Safety Goals or regulatory guides.

Based on guidance in draft Regulatory Guide DG-1145, the key objective of the ESBWR PRA is to use the available plant design information at the design certification phase and perform PRA analyses to show that the design meets the following goals:

(1) Core damage frequency (CDF) below 1E-4/yr

(2) Large release frequency (LRF) below 1E-6/yr (with a Conditional Containment Failure Probability (CCFP) of 0.1 or less)

(3) Frequency of radiation dose of 25 rem at the site boundary below 1E-6/yr

(4) Overall risks lower than the currently operating BWRs

(5) Assess non-safety functions requiring enhanced regulatory oversight

(6) Assess PRA findings not meeting the previous 5 goals (e.g. single failures that would prevent meeting any of these goals)

This section includes a summary of the following contributors to the ESBWR risk profile:

- Internal Events PRA – Section 17.1
- External Events Hazards Analysis – Section 17.2
- Low Power and Shutdown PRA – Section 17.3

This section also provides a summary of comparison with the Safety Goals in Section 17.4.

The ESBWR PRA uses the current information available for the ESBWR plant design, Technical Specifications, and procedures. Component failure data and initiating event frequencies are based on generic industry data with consideration of the ESBWR design. Given the state of the ESBWR plant design, the PRA analyses contain conservative elements (e.g., pre-initiator and post-initiator HEPs; maintenance unavailabilities; component failure rates; flood and fire initiation, propagation and impacts; ground level release and no evacuation warning assumed in consequence analysis; etc.). As such, the ESBWR risk profile is judged to be lower than the current quantitative results summarized here.

17.1 INTERNAL EVENTS PRA

Consistent with the Severe Accident Policy Statement for future plants, a PRA encompassing the Level 1, Level 2, and Level 3 aspects of internal event hazards at full power is developed for the ESBWR. Each of these aspects is discussed below.

17.1.1 Level 1 PRA

The Level 1 internal events evaluation quantifies the core damage frequency (CDF) due to internal event challenges occurring at full power. The Level 1 PRA modeling uses systemic fault tree logic and accident sequence event tree logic.

The MAAP code is used to perform the thermal hydraulic analysis of the RPV and containment to support the determination of functional and systemic success criteria and accident sequence timings.

The end state of the Level 1 PRA is core damage. Core damage accident categories are defined according to key accident parameters: RPV status, Containment status, and Reactor Power Level.

Table 17.1-1 summarizes the full power internal events CDF as a function of accident class. More details related to CDF and importance factors are available in Sections 7, 11, and 18.

17.1.2 Level 2 PRA

The ESBWR Level 2 PRA is a comprehensive analysis that assesses the key post-core damage phenomenological and systemic issues and quantifies multiple radionuclide release end states, including large release frequency.

The post-core damage accident progression is modeled using two types of containment event trees: Containment Phenomenology Event Trees (CPETs) and Containment System Event Trees (CSETs). These containment event trees are used to quantify the frequencies of the various radionuclide release end states.

The MAAP code is used to perform the thermal hydraulic analysis of the core melt progression and the fission product source term as a function of time and location. These source term calculations are used to support the characterization of the timing and release magnitude of the release categories, which is used as input to the Level 3 PRA.

Table 17.1-2 summarizes the full power internal events radionuclide release frequency as a function of release category. Table 17.1-3 summarizes the source terms for each of the radionuclide release categories.

Refer to Sections 8 and 9 for additional details.

17.1.3 Level 3 PRA

The Level 3 PRA consequence analysis assesses the public impact and frequency of the postulated radionuclide releases analyzed in the Level 2 PRA. The MACCS2 code is used to model and quantify the Level 3 PRA. The Level 2 release frequencies and source term fractions summarized in Tables 17.1-2 and 17.1-3 are used as input to the Level 3 analysis.

The end state for the consequence analysis is public risk, as measured by public dose and public fatalities (acute and latent).

Table 17.1-4 summarizes the key results of the full power internal events Level 3 PRA.

Refer to Section 10 for additional details and results.

17.2 EXTERNAL EVENT HAZARDS

The ESBWR is in the design stage and therefore, the precise layout and plant location is as yet unknown. The external hazard analyses are performed recognizing that the goal of the ESBWR is to design the plant and site such that external hazards are minimized.

The external hazards that are explicitly evaluated to determine their potential impact on risk are:

- Internal floods
- Internal fires
- High winds
- Seismic events

Other external event hazards are judged to be non-significant contributors to the ESBWR risk profile.

17.2.1 Internal Floods

The current plant design layout is used to define the internal flood challenges, propagation paths, and associated failures. A simplified bounding probabilistic flooding approach is employed using general design assumptions to identify potential flooding vulnerabilities. The flooding analysis addresses flood induced accidents occurring during full power and shutdown configurations.

The bounding analysis begins by assigning a flood initiation frequency to every flood scenario in a building that is equal to the entire flood initiation frequency for that building. The core damage frequency for each flood damage state is obtained via the quantification of the internal event PRA models. The internal event initiator and associated accident sequence structure that best represent the flood progression are used to model the flood. The damage caused by the flood is input into the accident sequence quantification by use of the selected initiator and/or with modifications to the accident sequence nodal fault trees, as appropriate. Following the accident sequence quantification, the flood scenario with the highest CDF in each building is used to represent the flood CDF for that building. The total flood risk is the sum of the CDFs of the bounding flood scenario for each building.

The internal flooding full power core damage frequency is 3.68E-09 per year, approximately an order of magnitude less than the internal events CDF. The internal flooding shutdown core damage frequency is 1.64E-09 per year, over an order of magnitude less than the internal events CDF.

Given the bounding nature of the analysis, it is judged that internal flood is a non-significant contributor to the ESBWR risk profile.

Refer to Sections 13 and 18 for more details and results.

17.2.2 Internal Fires

The ESBWR PRA includes an assessment of the contribution of fire induced core damage events. The current plant layout is used to define the internal fire challenges, fire ignition

frequencies, propagation paths, and associated failures. The internal fire PRA analysis quantifies the internal fire event trees using the appropriate system models with systems or trains failed due to the fire. The analysis is conservatively biased (i.e., bounding). This conservative assessment is considered biased or bounding due to multiple issues.

Given the current state of the plant design, a bounding approach is used. Some of the key bounding assumptions are:

- No credit is taken from fire suppression systems or fire brigades
- Fire ignitions are assumed to grow unchecked and disable all equipment in an area
- All fire-induced equipment damage occurs at t=0
- Hot short effects are included in the quantified model despite the incorporation of a fiber optic system for instrumentation and control that would preclude such effects

The analysis addresses fire-induced accidents occurring during full power and shutdown configurations.

The internal fires full power core damage frequency is 1.21E-08 per year. The internal fires shutdown core damage frequency is 2.32E-08 per year. These results are higher than the internal events CDF.

Given the bounding nature of the analysis, it is judged that more realistic analysis will reduce the calculated CDF; however, internal fires are expected to be significant contributors to the ESBWR risk profile, though less of a significant contributor than at current BWRs.

Refer to Sections 12 and 18 for more details and results.

17.2.3 High Winds

The current plant layout is used to define the high wind response and associated plant failures. The tornado hazard frequency is based on generic data. The tornado-induced plant impacts are based on a qualitative evaluation based on ESBWR plant design criteria. The internal events PRA accident sequence structures and system fault trees and success criteria are used in the calculation of the tornado CDF. Both at-power and shutdown tornado-induced accident scenarios are quantified.

The tornado full power core damage frequency is 4.77E-11 per year. The tornado shutdown core damage frequency is 8.67E-13 per year. These results are non-significant in comparison to the internal events CDF. Tornado risk is judged a non-significant contributor to the ESBWR risk profile.

Refer to Sections 14 and 18 for more details and results.

17.2.4 Seismic Hazard

The ESBWR seismic analysis is a seismic margins assessment (SMA) performed in Section 15 to show that the ESBWR plant and equipment are capable of withstanding an earthquake with a magnitude at least two times the safe shutdown earthquake. The SMA analysis calculates high confidence low probability of failure (HCLPF) accelerations for important accident sequences. No core damage frequencies are calculated as part of the ESBWR PRA seismic analysis.

The seismic margins analysis shows that no seismic-induced accident sequence has a HCLPF lower than 0.60g. As such, low magnitude seismic initiating events are not significant contributors to risk. High magnitude earthquakes, greater than 2 x SSE, are expected to be the major contributors to the seismic risk profile (this is consistent with past industry seismic PRAs).

Given the low seismic capacity of switchyard components, the majority of seismic events will result in a LOPP scenario.

The most limiting HCLPF sequences (both 0.62g HCLPF) are seismic-induced loss of DC power and seismic-induced ATWS due to seismic-induced failure of the fuel channels and seismic-induced failure of the SLCS tank. Each of these scenarios also involves seismic-induced LOPP.

Seismic risk is highly site specific. However, the ESBWR seismic design is robust, introducing very low risk contributors for most feasible sites. Seismic risk is judged to be a non-dominant contributor to the ESBWR risk profile.

Refer to Sections 15 and 18 for more details and results.

17.3 LOW POWER AND SHUTDOWN HAZARD

The current plant layout is used to define the shutdown challenges. Like the other aspects of the PRA, given the status of the ESBWR design, the shutdown risk assessment uses simplified bounding approaches. The shutdown PRA analysis quantifies the shutdown event trees using the appropriate system models with systems or trains failed or unavailable as dictated by the fault tree models or shutdown schedule.

The internal events shutdown CDF is calculated at 5.56E-09 per year. This result is less than the internal events CDF. More realistic analysis will further reduce the calculated CDF. Shutdown CDF is judged a non-significant contributor to the ESBWR risk profile.

Refer to Sections 16 and 18 for more details and results.

17.4 COMPARISON WITH SAFETY GOALS

17.4.1 Aggregation of Results

It is judged desirable to have the ability to calculate a single risk metric from all hazards and all modes of operation.

The purposes for computing risk metrics may be conveniently grouped into three categories:

(a) Comparison with safety goals

(b) Risk informed applications with regard to treatment of small changes in risk metrics (e.g., ΔCDF, ICCDP)

(c) Prioritization applications either on a relative basis (Maintenance Rule) or absolute basis (SAMA, a (4))

Interfacing with these purposes are the "criteria" that have been developed, e.g., safety goals or acceptance guidelines.

The overall safety goals are closely tied to what is perceived as acceptable risk levels. Acceptance guidelines or surrogate safety goals that appear in Regulatory Guides have been derived using subjective judgements and include varying levels of conservatisms.

While it is desirable from a variety of risk management perspectives to aggregate the various risk contributors into a single risk metric, there are practical resource and technological issues that prevent meaningful aggregation in all cases. Where aggregation is not performed carefully, biased risk metrics can result in conservative or non-conservative decision-making. Future improvements in PRA technology as well as increased resources could mitigate much of the reasons for not aggregating. However, it is envisioned that not all the technological issues will be solved and that there will always be cases where aggregation is not prudent.

Internal events PRA models have been developed and used by the NRC and industry for more than 30 years. In addition, a PRA Standard for internal events is available and endorsed by the NRC in RG 1.200. The comfort level and confidence in internal events Level 1 exceeds that for other events for which the experiential evidence is significantly less.

On the other hand, external events have used conservative screening techniques to reduce resource expenditures at the cost of introducing conservative biases, and currently there are no endorsed PRA Standards.

There are distinct differences in the level of bias that are currently included in typical (not all) external events and shutdown PRAs compared with internal events analysis.

By virtue of the conservative biases that are superimposed on the external event and low power shutdown risk analyses, the risk metrics calculated from these models are unacceptably biased and not comparable to the internal events PRA model risk metrics.

Therefore, the usefulness of the aggregation of the numerical risk metrics from each of the applicable hazards and operating modes has significant limitations using current PRA models.

Each PRA contributor is modeled with its own unique set of biases that make the results conservative, realistic, or non-conservative. By attempting to add these separate contributors these biases may overwhelm the quantitative characterization. Treating the contributors

separately allows these biases to be considered and evaluated under the specific constraints of an application.

The internal events PRA is generally considered to have the lowest bias and most robust risk profile.

External events and shutdown PRAs are judged to have varying degrees of conservative bias that may distort the decision-making process. The decision-maker must be informed of the biases in each of these contributors to adequately support risk-informed decisions.

17.4.2 Comparison with Safety Goals

Based on the above, it is judged appropriate to treat each of the risk profile contributors separately in comparison to the safety goals.

The results of the full power internal events PRA are compared against the safety goals in Table 17.4-1. As can be seen from Table 17.4-1, the safety goals are met with significant margin.

The full power internal events CDF is greater than three orders of magnitude below the 1E-4/yr safety goal.

Large early release (LRF) is conservatively defined in this analysis as releases greater than Technical Specification leakage (i.e., releases greater than release category TSL). Even with this conservative definition, the full power internal events LRF is greater than three orders of magnitude below the 1E-6/yr safety goal.

Section 8.2.1.5 shows that ESBWR containment effectiveness for full power internal events is 0.97, which translates to a 0.03 Conditional Containment Failure Probability (CCFP). This meets the safety goal of CCFP < 0.1 with significant margin.

Section 10 summarizes the annual exceedance frequency of a radiation dose of 25 rem at the reactor site boundary (the analysis uses a radius of 0.5 miles as the site boundary). This risk metric for the full power internal events also meets the safety goal with significant margin.

The external events CDF and internal events shutdown CDF, as discussed in the previous sections, also individually meet the CDF safety goal. Level 2 and Level 3 results for these risk contributors are not calculated.

However, based on the conservative approaches to the external events and shutdown analyses as discussed earlier in this section and the wide margin with which the ESBWR internal events risk profile meets the safety goals, it is judged that the combined risk profile of internal events, external events and shutdown events also meets the safety goals.

Table 17.1-1

Full Power Internal Events CDF Contribution by Accident Class[(1)]

ACCIDENT CLASSES		CDF [/yr]	CONTRIBUTION
CDI	CD at low RPV pressure and containment intact	2.86E-08	97.95%
CDIII	CD at high RPV pressure with containment intact	4.11E-10	1.41%
CDIV	CD resulting from failure to insert negative reactivity in ATWS conditions	1.83E-10	0.63%
CDV	Containment bypassed at the beginning of the accident	4.27E-12	0.01%
	Total	2.92E-08	100.00%

Note:

(1) See Sections 3 and 7 for definitions of parameters in this table and related details.

Table 17.1-2

Full Power Internal Events Radionuclide Release Category Frequencies(1)

Source Term	Radionuclide Release Category	Representative MAAP CASE	Release Frequency (per year)
1	BOC	BOCsd_nIN	4E-12
2	BYP	T_nIN_BYP	1E-12
3	CCID	T_nIN_nD_CCID	2.9E-11
4	CCIW	T_nIN_CCIW	2.9E-10
5	DCH	T_nDP_nIN_nD_DCH	<1E-12
6	EVE	T_nIN_nD_EVE	2.5E-10
7	FR	T-AT_nIN_nCHR_FR	2.3E-10
8	OPVB	T_nDP_nIN_VB	<1E-12
9	OPW1	T_nDP_nIN_nCHR_W1	<1E-12
10	OPW2	T_nDP_nIN_nCHR_W2	1.4E-11
11	TSL	T-AT_nIN_TSL2x	2.8E-8

Note:

(1) See Section 9 for definition of parameters in this table. Also see related details in Sections 8, 9 and 10.

Table 17.1-3

Full Power Internal Events Fission Product Release Fractions(1)

Radionuclide Source Terms (Release Fraction 24 hours after onset of core damage)

Release Category	Xe/Kr	CsI	TeO_2	SrO	MoO_2	CsOH	BaO	La_2O_3	CeO_2	Sb	Te_2	UO_2
BOC	1.0E+00	8.5E-01	7.5E-01	1.5E-02	7.2E-02	3.8E-01	1.5E-02	6.1E-04	3.4E-03	1.5E-01	6.1E-03	2.9E-05
BYP	9.7E-01	4.0E-01	1.9E-01	1.6E-02	1.2E-01	3.5E-01	2.9E-02	5.3E-04	3.3E-03	2.4E-01	4.3E-03	2.4E-05
CCID	9.1E-01	6.9E-02	6.8E-02	2.2E-06	4.7E-06	2.8E-02	1.3E-05	1.3E-07	1.0E-06	1.5E-01	1.4E-02	2.3E-07
CCIW	9.1E-01	8.0E-04	5.9E-05	1.4E-06	4.5E-06	7.6E-04	1.1E-06	1.3E-07	7.6E-07	2.6E-03	3.1E-05	7.9E-09
DCH	9.0E-01	4.5E-01	1.2E-01	3.2E-04	2.7E-04	6.2E-02	3.1E-04	3.1E-04	3.2E-04	8.1E-02	1.1E-04	9.6E-08
EVE	8.3E-01	2.5E-02	6.4E-02	1.3E-02	1.1E-04	7.1E-02	5.7E-03	8.2E-04	6.2E-03	2.1E-01	6.8E-03	5.0E-05
FR	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
OPVB	9.1E-01	3.6E-04	8.2E-04	1.4E-04	1.2E-04	4.9E-03	1.4E-04	1.4E-04	1.4E-04	1.7E-03	2.4E-05	0.0E+00
OPW1	1.9E-01	1.7E-04	2.4E-04	6.0E-07	2.0E-07	5.7E-04	5.8E-07	6.0E-07	6.0E-07	1.3E-02	2.6E-06	0.0E+00
OPW2	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00	0.0E+00
TSL	2.0E-03	1.5E-04	9.5E-05	2.1E-06	3.9E-05	5.3E-05	7.7E-06	7.3E-08	2.0E-07	9.9E-05	4.6E-08	1.0E-10

Note:

(1) See Section 9 for definition of parameters in this table. Also see related details in Sections 8, 9 and 10.

Table 17.1-4

Full Power Internal Events Consequence Analysis Results

End State	24 Hours After Onset of Core Damage (per year)	72 Hours After Onset of Core Damage (per year)
Individual Risk(1) (0 – 1 Mile)	2.6E-11	3.7E-11
Societal Risk(2) (0 – 10 Mile)	4.8E-12	6.0E-12
Radiation Dose Probability at 0.25 Sv(3) (0 – 0.5 Mile)	2.2E-09	3.1E-09

Notes:

(1) Early fatality risk per year per individual living within 1 mile of the site.

(2) Latent fatality risk per year per individual living within 10 miles of the site.

(3) Annual exceedance frequency of a 0.25 Sv (25 REM) radiation dose at 0.5 miles.

Table 17.4-1

Safety Goal Comparison Based on Internal Events PRA

Goal	ESBWR Full Power Internal Events PRA Results[3]	Safety Goal Achieved
Core Damage Frequency (CDF) < 1E-4/yr	2.92E-08[2]	YES
Large Release Frequency (LRF) < 1E-6/yr[1]	8.0E-10	YES
Conditional Containment Failure Probability (CCFP) < 0.1	0.03	YES
0.25 Sv Radiation Dose at Side Boundary <1E-6/yr	2.2E-09 (24 hrs) 3.1E-09 (72 hrs)	YES

Notes:

(1) Large Release is conservatively defined in this analysis as releases greater than Technical Specification leakage (i.e., releases greater than release category TSL).

(2) The external events and shutdown PRA results also meet the CDF safety goal. Level 2 and Level 3 results are not calculated for these aspects of the PRA.

(3) Based on the conservative approaches to the external events and shutdown analyses as discussed earlier in this section and the wide margin with which the ESBWR internal events risk profile meets the safety goals, it is judged that the combined risk profile of internal events, external events and shutdown events also meets the safety goals.