APR1400 Design Certification Severe Accident Mitigation Design Alternatives
Technical Analysis In Support of the Environmental Assessment

1 Introduction

On December 23, 2014, Korea Hydro & Nuclear Power, Inc., hereinafter referred to as KHNP or the applicant, tendered its application for certification of the Advanced Power Reactor 1400 (APR1400) standard nuclear reactor design with the U.S. Nuclear Regulatory Commission (the NRC or Commission). The applicant submitted this application in accordance with Title 10 of the *Code of Federal Regulations* (10 CFR) Part 52, "Licenses, Certifications, and Approvals for Nuclear Power Plants," Subpart B, "Standard Design Certifications." The application included the APR1400 design control document (DCD), the APR1400 probabilistic risk assessment (PRA) and the APR1400 Environmental Report (ER). The NRC formally docketed the application for design certification (DC) on March 4, 2015, under Docket No. 52-046.

The APR1400 is an approximately 4,000-MW-t pressurized-water reactor (PWR) and an evolutionary change from light-water reactor designs of plants that have been licensed and in commercial operation before April 18, 1989. As presented in Chapter 1 of the DCD (KHNP 2018c), the safety design objectives of the APR1400 are as follows:

- Simplify plant design and operation;
- Provide the proper safety margin for a more forgiving and resilient plant;
- Improve the human-system interface system to promote error-free normal operations and quick, accurate diagnosis of off-normal conditions;
- Meet applicable NRC requirements related to engineered safety system design and analysis of plant and engineered safety system responses to regulatory transients and accidents;
- Evaluate the mean annual core damage frequency (CDF) and large release frequency (LRF) for the APR1400 design using a PRA. The design target for CDF is 1×10^{-5} events per reactor year, and the design target for LRF is 1×10^{-6} events per reactor year;
- Provide a large, rugged reactor containment building and associated containment systems for heat removal and retention of fission products for design basis events (DBEs) and beyond DBEs (BDBEs). Containment design pressure is based on the most limiting loss of coolant or steam line break accident;
- Provide containment system components for which a change of state is necessary (e.g., containment isolation valves) that are redundant and sufficiently independent from the systems whose failure could lead to core damage in order to provide reasonable assurance of an intact containment and avoid significant vulnerability to common cause failure;
- Design the containment systems so the applicable exposure limits are met assuming a reactor containment building design leak rate of no less than 0.1 volume percent per day;
- Provide at least two separate and independent alternating current power connections to the grid to decrease the likelihood of a loss of offsite power (LOOP);
- Reduce the risk of a station blackout (SBO) by providing an independent, safety-related, onsite ac power generation source for each division and by providing a non-safety-related, alternate alternating current (AAC) onsite power source; and

- Provide adequate severe accident protection through conservatisms inherent in the design and additional plant features that limit direct containment heating, provide reasonable assurance of core debris coolability, and avoid detonable concentrations of hydrogen.

In accordance with 10 CFR 52.47(b)(2) and 51.55(a), the APR1400 DC application included the following report: "Applicant's Environmental Report - Standard Design Certification" (KHNP 2014a) with two subsequent revisions (KHNP 2018a, 2018e). This report provides an evaluation of severe accident mitigation design alternatives (SAMDAs) for the APR1400 design to ensure that plant design changes which may have the potential for improving severe accident performance are identified and evaluated. The evaluation addresses the potential costs and benefits of SAMDAs for the APR1400 design.

The purpose of this technical analysis report is to document the staff's review of KHNP's consideration of SAMDAs which included identifying a broad range of potential alternatives, then determining whether implementation of the alternative would be feasible and beneficial on a cost-risk reduction basis.

1.1 Severe Accident Mitigation Alternatives and Severe Accident Mitigation Design Alternatives

The term severe accident mitigation alternatives (SAMAs) refers to an additional feature or action which would prevent or mitigate the consequences of severe accidents. SAMAs would include the consideration of hardware modifications or design alternatives, procedure changes, and training program improvements. SAMDAs are a subset of SAMAs with just the consideration of hardware modifications or design alternatives.

The purpose of the evaluation of SAMAs is to determine whether there are SAMDAs, procedural modifications, or training activities that can be justified to further reduce the risks[1] of severe accidents (i.e., the prevention of core damage or reducing the release to the surrounding environment of radioactive material resulting from core damage). For standard DCs, the assessment is only for SAMDAs because a DC applicant cannot assess changes in operating procedures and training programs. This is because these programs have not been developed at this stage of licensing. Rather, they are developed during the construction phase of a nuclear power plant as a licensee prepares for the beginning of operations for the selected reactor design. However, it is expected that risk insights would be considered by a licensee in the development of plant procedures and training.

Consistent with the objectives of standardization and early resolution of design issues, the Commission decided to evaluate SAMDAs as part of the DC for the APR1400 design. There are several Commission policy statements, court actions, and a staff recommendation (SECY) that establishes the basis to evaluate SAMDAs for a standard DC. In 1980, the Commission issued a policy statement on the consideration of severe accidents in Environmental Impact Statements (EISs) for new reactor applications submitted after July 1, 1980 (45 FR 40101, June 13, 1980). In a 1985 policy statement (50 Fed. Reg. 32,138; August 8, 1985), the Commission defined the term severe accident as an event that is beyond the substantial coverage of design basis events, including events where there is substantial damage to the reactor core (whether or not there are serious offsite consequences). A 1989 court decision ruled that the consideration of SAMAs is required for plant operation (Limerick Ecology Action v. NRC, 869 F.2d 719 (3rd

[1] Risk is defined as the probability of an accident multiplied by the magnitude of the consequences.

Cir. 1989)). Subsequently, in the Staff's Requirements Memorandum to SECY-91-299 (ADAMS Accession Number ML003707922), the Commission approved:

- Addressing SAMDAs for certified designs in a single rulemaking process that would consider both the 10 CFR 50.34(f) and the National Environmental Policy Act requirements in the 10 CFR Part 52 DC rulemaking;
- Consideration of the costs and benefits associated with the review of the SAMDAs for the standard plant DCs; and
- Directed the staff to advise applicants for a DC that they will be required to assess SAMDAs and the applicable decision rationale as to why they will or will not benefit the safety of their designs.

As a result of the above, and other Commission actions, 10 CFR 52.47(a)(23) requires that applications to the NRC for a reactor DC include "a description and analysis of design features for the prevention and mitigation of severe accidents…." In addition, 10 CFR 52.47(a)(27) requires a description of a "plant-specific probabilistic risk assessment (PRA) and its results," and, under 10 CFR 52.47(b)(2), an application for a standard DC must contain an environmental report (ER) as required by 10 CFR 51.55. This ER, pursuant to 10 CFR 51.55(a), must "address the costs and benefits of severe accident mitigation design alternatives, and the bases for not incorporating severe accident mitigation design alternatives in the design to be certified."

1.2 APR1400 Probabilistic Risk Assessment

For the DC application, KHNP performed a PRA for the APR1400 design to achieve the following objectives:

- Identify the dominant severe accident sequences, which are those that account for most of the CDF and associated source terms for the design;
- Modify the design, on the basis of PRA insights, to prevent severe accidents or mitigate their consequences, and thereby reduce the risk of such accidents; and
- Provide a basis for concluding that all reasonable steps have been taken to reduce the chances of occurrence, and mitigate the consequences, of severe accidents.

KHNP's PRA analysis is described in Chapter 19 of the APR1400 DCD, "Probabilistic Risk Assessment and Severe Accident Evaluation," (KHNP 2018d) with the appropriate Level 1 and Level 2 PRA results being applied as part of the environmental assessment in support of the APR1400 SAMDA evaluation. KHNP provided their assessment of SAMDAs in the APR1400 DCA ER as supported by the Technical Report (TR), "Severe Accident Mitigation Design Alternatives (SAMDAs) for the APR1400" (KHNP 2014b, 2018b, 2018f).

1.3 Review Guidance

The staff reviewed the technical content of KHNP's ER and TR along with developing requests for additional information (RAIs) using guidance from NUREG–1555, *Standard Review Plans for Environmental Reviews for Nuclear Power Plants: Environmental Standard Review Plan* (NRC 2000). Specifically, Section 7.2, "Severe Accidents," for the analysis of offsite consequences and Section 7.3, "Severe Accident Mitigation Alternatives," for the identification and evaluation of design alternatives that reduce the radiological risk from a severe accident by preventing substantial core damage. The staff also applied the guidance in NUREG/BR-0058, Rev. 4 (NRC 2004), which establishes a framework for evaluation of SAMAs including estimation of values and impacts for design alternatives and the "dollars per person-rem" conversion factors and NUREG/BR-0184 (NRC 1997) with respect to the cost-benefit methodology. An environmental audit was conducted in accordance with NRO Office Instruction NRO-REG-108, Regulatory Audits (NRC 2009).

In addition to the above guidance documents, KHNP also applied guidance from NEI 05-01A, "Severe Accident Mitigation Alternatives (SAMA) Analysis – Guidance Document" (NEI 2005). This guidance is an acceptable methodology to the NRC for the assessment of SAMAs for license renewals under 10 CFR 51.53(c)(3)(ii)(L), but has not been endorsed or accepted for the assessment of new reactor SAMDAs under 10 CFR 51.55(a). However, the staff recognizes that there is useful information and guidance contained in NEI 05-01A. For example, the application of the cost formulas from NUREG/BR-0184 for assessing the maximum benefit, the identification of SAMDAs, and the process for screening and assessing whether a SAMDA is potentially cost-beneficial. Therefore, the staff accepts the application of NEI 05-01A in the manner by which KHNP applied the guidance for this SAMDA assessment.

1.4 Environmental Review Process

The staff conducted the environmental review of the APR1400 DC and the development of an environmental assessment in accordance with 10 CFR 51.30(d). Based on a review of the APR1400 ER, the staff developed a number of information needs in preparation for an environmental audit (NRC 2015a), developed an audit plan (NRC 2015b), conducted the audit from September 9, 2015, to September 30, 2015, as documented in an audit summary report (NRC 2015c), and issued RAIs for KHNP to addressed based on the results of the audit as shown in Table 1.4-1. Since several of the RAIs were dependent on information from the Level 1 and Level 2 PRAs, which the staff is reviewing in parallel to the environmental review, several RAI responses were not provided until January 2018. KHNP also provided two additional clarifications after January 2018 based on the staff's feedback to one RAI response and to the replacement power cost in Revision 2 to the ER and TR (KHNP 2018e and KHNP 2018f). Based on the information provided in the ER and TR, the results of the environmental audit, RAI responses and clarifications, and other independent sources of information available to the staff; the evaluation of the APR1400 SAMDA analysis is presented below.

Table 1.4-1 APR1400 DC Environmental RAIs and Responses

RAI ID No.	RAI Question No.	Question Summary	RAI Issue Date	RAI Accession No.	RAI Response Date	RAI Response Accession No.
8428	EIS ACC/SA-1	Rationale for selecting the year 2030 as the year of maximum environmental impacts.	3/22/2016	ML16082A353	7/1/2016	ML16183A238
8428	EIS ACC/SA-2	Justification of the use of an older version of the SecPop computer code.	3/22/2016 3/22/2016	ML16082A353 ML16082A353	1/3/2018 11/28/2016	ML18003B412 ML16333A458
8428	EIS ACC/SA-3	Explanation of the population values for each grid element (or rosette segment) t from SecPop2000 for extrapolation to the year 2030.	3/22/2016 3/22/2016	ML16082A353 ML16082A353	1/2/2018 12/5/2016	ML18002A566 ML16340B362
8428	EIS ACC/SA-4	Information applied from the Level 2 PRA analysis to be used as input to the severe accident consequence analyses for each of the event categories (at-power and LPSD) and source term categories (STC01 to STC21).	3/22/2016 3/22/2016	ML16082A353 ML16082A353	1/3/2018 3/21/2017	ML18003B412 ML17080A080
8428	EIS ACC/SA-5	Summary of the basis and details on the data sources used for determining the base risk, including such site data as meteorological, population, and land use data and design specific information from the Level 1 and Level 2 PRAs including source documentation and references.	3/22/2016 3/22/2016	ML16082A353 ML16082A353	9/15/2017 7/1/2016	ML17262B210 ML16183A238
8428	EIS ACC/SA-6	Discuss the atmospheric, surface water, and groundwater pathways applied in the severe accident analysis and what the resulting impacts were from these pathways.	3/22/2016 3/22/2016	ML16082A353 ML16082A353	1/18/2018 7/1/2016	ML18018B378 ML16183A238

Table 1.4-1 Cont'd

RAI ID No.	RAI Question No.	Question Summary	RAI Issue Date	RAI Accession No.	RAI Response Date	RAI Response Accession No.
8428	EIS ACC/SA-7	Discussion of the socioeconomic, individual and population health risks from the postulated APR1400 severe accidents.	3/22/2016	ML16082A353	12/5/2016	ML16340B362
8428	EIS ACC/SA-8	Discussion on the dominant severe accident sequences for large release evaluated from the Level 2 PRA and how they were determined.	3/22/2016	ML16082A353	11/28/2016	ML16333A458
8428	EIS ACC/SA-9	Discussion on the analytical process used for determining the risks from severe accidents.	3/22/2016 3/22/2016	ML16082A353 ML16082A353	1/8/2018 7/1/2016	ML18018B378 ML16183A238
8428	EIS ACC/SA-10	Justification for the setting of MACCS input parameter RDPLHEAT to 0.00 watts is conservative or provide analysis to justify the plume heat used in the MACCS calculations.	3/22/2016	ML16082A353	3/21/2017	ML17080A080
8428	EIS ACC/SA-11	Basis for the statement that "Economic costs are the recommended MACCS values as given for the NUREG-1150 study as updated using recent Consumer Price Indexes from the Bureau of Labor" versus using current local or regional values for the Surry site.	3/22/2016	ML16082A353	11/28/2016	ML16333A458
8428	EIS ACC/SA-12	Provide the source of information and specific references regarding the data and results from the Level 1 PRA documents, Level 2 PRA documents, and supporting Level 3 PRA documents that are mentioned throughout the ER.	3/22/2016	ML16082A353	1/2/2018	ML18002A551

Table 1.4-1 Cont'd

RAI ID No.	RAI Question No.	Question Summary	RAI Issue Date	RAI Accession No.	RAI Response Date	RAI Response Accession No.
8428	EIS ACC/SA-13	Definition for "Group Controller Level 3 analysis" (see page 3 of ANR1400-E-NR-14006-p).	3/22/2016	ML16082A353	7/1/2016	ML16183A238
8428	EIS ACC/SA-14	References for specific information applied in the base risk for the SAMDA analysis.	3/22/2016 3/22/2016	ML16082A353 ML16082A353	7/1/2016	ML16183A238
8428	EIS ACC/SA-15	Revised base case analysis with a non-evacuating cohort with appropriate justification and supporting references.	3/22/2016 3/22/2016 3/22/2016	ML16082A353 ML16082A353 ML16082A353	6/22/2018 1/2/2018 9/15/2017 11/28/2016	ML18178A576 ML18002A571 ML17262B210 ML16333A458
8429	EIS ACC/SAMDA-1	Documentation on the basis as why costs are excessive or benefits negligible for certain SAMDAs and identify the specific SAMDAs that were not screened out.	3/22/2016	ML16082A474	1/2/2018	ML18002A559
8429	EIS ACC/SAMDA-2	Justification (i.e., the methodology and the source documents) for inclusion of each basic event discussed in Section 7 of TR for considered as SAMDAs.	3/22/2016	ML16082A474	1/2/2018	ML18002A559
8429	EIS ACC/SAMDA-3	Baseline implementation cost in U.S. dollars for each SAMDA not screened out in ER Table 4 and for the basic events used to evaluate SAMDA benefit in Section 7 of the TR.	3/22/2016	ML16082A474	1/2/2018	ML18002A559
8429	EIS ACC/SAMDA-4	Documentation in the ER or TR to explain the purpose and development of Tables 5a through 5f and Tables 6a through 6f.	3/22/2016 3/22/2016	ML16082A474 ML16082A474	1/2/2018 9/15/2017 12/19/2016	ML18002A574 ML17261B283 ML16354A472
8429	EIS ACC/SAMDA-5	Documentation on the process the expert panel followed and the selection of design-specific SAMDA items.	3/22/2016	ML16082A474	9/15/2017	ML17262A358
8429	EIS ACC/SAMDA-6	Source document(s) and the pages in these documents for the approximately 540 SAMDA items from the PRA results.	3/22/2016	ML16082A474	1/2/2018	ML18002A559

Table 1.4-1 Cont'd

RAI ID No.	RAI Question No.	Question Summary	RAI Issue Date	RAI Accession No.	RAI Response Date	RAI Response Accession No.
8429	EIS ACC/SAMDA-7	Documentation of all of the subsections in Section 7 cited to a SAMDA in TR Table 4 or to a basic event in Table 5.	3/22/2016	ML16082A474	3/16/2017	ML17075A430
8429	EIS ACC/SAMDA-8	Update ER and SAMDA analysis to reflect changes to plant systems, configurations, and analyses for the APR1400 design.	3/22/2016	ML16082A474	1/2/2018	ML18002A559
8655	EA ACC/SAMDA-1	Sensitivity analysis based on the decision CLI-16-07 (NRC 2016) regarding MACCS input parameters TIMDEC and CDNFRM for the applied MACCS input parameter DF levels.	9/7/2016	ML16335A420	1/2/2018	ML18002A556

2 Estimate of Risk for APR1400

In Section 3, Base Risk of the ER and the TR, the applicant provides a summary of the application of the APR1400 Level 1 PRA and Level 2 PRA models described in APR1400 DCD Chapter 19 for the risk information utilized in the assessment of APR1400 SAMDAs (KHNP 2018e and KHNP 2018f). The PRA provides an evaluation of the risk of core damage and release of radioactive material associated with both internal and external events that can occur during plant operation at power or while shutdown. As previously discussed, APR1400 DCD Chapter 19 summarizes the information regarding the PRA models and severe accident evaluations conducted by the applicant in support of DC of the APR1400 reactor (KHNP 2018d). Based on the guidance in NURG-0800, Standard Review Plan (SRP) Chapter 19, "Severe Accidents," the staff's review of APR1400 DCD Chapter 19 with their regulatory findings are presented in the staff's Final Safety Evaluation Report (FSER) Chapter 19 (NRC 2018a).

2.1 Application of the APR1400 PRA

The APR1400 PRA comprises two major areas of analysis: (1) identification of sequences of events that could lead to core damage and estimation of their frequencies of occurrence (the Level 1 PRA analysis); and (2) evaluation of the potential response of the containment to these sequences, with emphasis on the possible modes of containment failure and the corresponding radionuclide source terms (the Level 2 PRA analysis). The APR1400 Level 1 and Level 2 PRA models quantified six risk categories, three for operations at-power and three for low-power and shutdown (LPSD) operations, namely:

- At-power internal events;
- At-power internal flooding events;
- At-power internal fire events;
- LPSD internal events;
- LPSD internal flooding events; and
- LPSD internal fire events.

The risks from other external events, such as high winds, external floods, external fires, etc., were determined to be insignificant and were not further analyzed under the SAMDA assessment. As determined by the APR1400 PRA model, CDF values were calculated for each of the risk category for 19 source term categories (STCs). KHNP originally assigned 21 STCs; however, two STCs (Nos. 12 and 15) were found not to contain any Level 2 PRA sequences and were assigned CDFs of zero. CDFs from the Level 1 PRA model for each risk category were binned into the 19 STCs with the results shown in Tables 1a and 1b of the ER and TR (KHNP 2018e and KHNP 2018f).

Each STC has a representative release determined as part of the Level 2 PRA model. This includes representative accident sequences from each STC with timing and release characteristics values for representative fission product groups applied in the offsite consequence analysis. The representative accident sequence was derived from a grouping process based on similarities in accident characteristics. As presented in Section 19.1.4.2.1.1, "Plant Damage State Analysis," of the APR1400 DCD (KHNP 2018d):

> …[M]any of the initiating events defined for the core damage sequences in the Level 1 analyses actually represent groups of different specific initiators that have similar effects

on the systems required to respond to them. This grouping process is used primarily to make the overall analysis process more efficient and tractable by limiting the number of discrete events and scenarios that must be considered, while retaining the degree of discrimination needed to capture differences in potential accident sequences.

APR1400 DCD, Section 19.1.4.2.1.3, provides further details on how the applicant binned the accident sequences into each STC (KHNP 2018d).

As discussed in Section 3 of the ER and TR, the applicant applied the Modular Accident Analysis Program (MAAP) code in analyzing the Level 2 PRA, which is used for phenomenological evaluation of the severe accident progression and for assessing the source term releases from containment. Additional information about how KHNP applied the MAAP code for the Level 2 PRA and subsequent source term information can be found in APR1400 DCD Sections 19.1 and 19.2. As noted in the staff's FSER Chapter 19, MAAP is an acceptable code to the staff (NRC 2018a). The timing and release information from the MAAP code was transcribed into a format acceptable for use by the offsite consequence code package known as MELCOR Accident Consequence Code System (MACCS). The resulting MACCS-formatted radionuclide release fractions and plume segment information for each STC are provided in Appendix A Tables 5.1-1 and 5.1-2 of the TR (KHNP 2018f).

During the DCD Chapter 19 safety review, the staff evaluated the applicant's Level 1 and Level 2 PRA models, and identified several issues that were not adequately addressed in the initial APR1400 DCD, Rev. 0, submittal. The applicant addressed all of these issues adequately through its responses to the staff's questions raised during the associated regulatory audit and RAIs. Based on its review, the staff found that the applicant adequately addressed the Commission's objectives regarding the prevention and mitigation of severe accidents (NRC 2018a). The staff concluded in Chapter 19 of the FSER (NRC 2018a) that the applicant properly assessed the APR1400 severe accidents in compliance with applicable NRC regulations, and in conformance with associated Commission policies and staff guidance found in NUREG-0800, SRP, Chapter 19. Therefore, the staff determined that the Level 1 and Level 2 PRA modeling information provided in the ER and associated TR are reasonable to be applied in support of the applicant's APR1400 SAMDA assessment.

2.2 Offsite Consequences and Risk Analysis

In order to evaluate the SAMDAs for its design, the applicant developed certain surrogate site information[2] along with other radiological health and economic cost information necessary for the appropriate computer code package to assess the offsite consequences of potential severe accidents for the APR1400 design. The applicant applied WinMACCS[3] Version 3.10 to determine the offsite consequences (i.e., a Level 3 PRA) from potential releases of radioactive material. WinMACCS Version 3.10 was also applied by the staff for their independent evaluation of the APR1400 SAMDA assessment. As such, MACCS requires the following:

- Specific design-based information regarding the released source term;
- Site information concerning meteorology, population distribution, economic data for the surrounding area, and appropriate emergency planning zone information; and

[2] The surrogate site may also be denoted as a "representative" or as a "generic" site since an actual site is not being proposed for building the APR1400 reactor design in the design certification application.
[3] WinMACCS is a Window-based version of the MACCS code package (Chanin and Young 1998). From herein, the report will use the title MACCS to denote the code.

- Input parameter values regarding acute and chronic health effects from radiation exposure.

MACCS applies this information for assessing the atmospheric transport of the released radioactive material, determining the appropriate mitigative actions based on dose projections (evacuation, relocation, food interdiction, etc.), dose accumulation by a number of pathways including food and water ingestion, early and latent health effects, and economic costs.

2.2.1 Site Selection and Site Parameters

KHNP selected the Surry Power Station site as their surrogate or representative site for the purposes of assessing the offsite consequences for the APR1400 SAMDA assessment. This site was analyzed as part of the severe accident assessment documented in NUREG-1150, "Severe Accident Risks: An Assessment for Five U.S. Nuclear Power Plants," (NRC 1990) and the follow-on study to NUREG-1150 known as the State-of-the-Art Reactor Consequence Analyses (SOARCA) published in NUREG-1935 (NRC 2012). Thus, this site has publicly available data sources and publicly available documents listing the MACCS input parameter values (see Appendix C of SNL 2013). Based on its review of the KHNP submissions, including RAI responses, the staff concludes that the applicant's selection of the Surry site is acceptable for assessing the offsite consequences for the APR1400 reactor design.

The ER and TR discuss in Section 3 of each document the application of the available Surry site data for use in the APR1400 MACCS calculations (KHNP 2018e and KHNP 2018f). Additional details are presented in Appendix A of the TR on the methodology and results for modifying certain segments of the site data to current and future year values (KHNP 2018f). The meteorological data was directly applied from NUREG-1150 based information that has been incorporated into a sample problem included in the MACCS installation package. For population distribution, land use, and economic data in the surrounding area of the Surry site, the applicant originally applied the Sector Population, Land Fraction, and Economic Estimation Program (SecPop) for the year 2000 U.S. Census (NRC 2003). But in response to staff RAI 8428 EIS ACC/SA-2 (see Table 1.4-1), KHNP later used SecPop Version 4.3. SecPop Version 4.3 can perform calculations with 2010 and 2000 population data and 2012, 2007, and 2002 economic data based on U.S. Census Bureau data and appropriate U.S. government economic databases. In response to staff RAI 8428 EIS ACC/SA-3 (see Table 1.4-1), KHNP provided additional details and information in Appendix A, Section 5, of the TR on extrapolation of site information to the future year of 2030 based on existing demographic databases for the two states, Virginia and North Carolina, whose counties are within a 50-mile radius of the Surry site (KHNP 2018f). The staff accepts the use of this information in the SAMDA evaluation.

2.2.2 MACCS Input Quantification

In addition to the establishing site parameters, the applicant also has to set the input parameter values for the other MACCS code modules, namely for the EARLY and CHRONC modules (Chanin and Young 1998). The EARLY module assesses the time period immediately following a radioactive release. This module is where the source term and plume segment values are provided to the MACCS code. Additionally, the EARLY module specifies the emergency response scenarios to be considered; including evacuation, sheltering, and dose-dependent responses. The CHRONC module evaluates the events following the emergency phase analyzed by the EARLY module. This includes total accumulated population dose, long term protective actions, individual health effects, and the economic costs related to the long-term protective actions. Current guidance for quantification of MACCS input parameters can be found in Sprung et al. 1990. The current version of MACCS does have input parameters that are not discussed in Sprung et al. 1990, and appropriate values would need to be assigned to these input parameters, such as from recent NRC studies (e.g., the SOARCA study documentation in NUREG/CR-7110 Volume 2 (SNL 2013)). KHNP applied input parameter values based on the current guidance documents with adjustments of the economic input parameters based on the Consumers' Price Index to bring them closer to 2016 dollar values. The MACCS input values for the APR1400 offsite consequences base case can be found in the MACCS input listing of Attachment III to Appendix A of the TR (KHNP 2018f).

2.2.3 Base Case and Sensitivity Cases

2.2.3.1 KHNP's Offsite Consequence Analyses

KHNP performed several offsite consequence calculation with the MACCS code package. A summary of the calculations is provided in Section 7 of Appendix A of the TR (KHNP 2018f). A base case relied upon expected or recommended input parameter values. The offsite consequences for population doses and offsite property damage costs for each STC were multiplied by the STC's CDF to obtain the appropriate risk value (person-rem per reactor year for population dose and dollars per reactor year for offsite property damage) for each STC. ER and TR Tables 3a through 3f for at-power risk categories, and Tables 4a through 4f for LPSD risk categories provide the results by STC and totals for both the consequence and risk values. These results from the base case calculation were applied as inputs to the averted[4] public exposure and averted public offsite property damage costs (see Sections 4 and 10 of KHNP 2018e and KHNP 2018f along with Section 6 of this report).

To assess how changes to important MACCS input values would affect the offsite consequence results, KHNP performed nine sensitivity calculations which are also discussed in Section 7 of Appendix A of the TR (KHNP 2018e, 2018f) with an additional case based on a staff clarification of an RAI response to RAI 8655 EA ACC/SAMDA-1 (See Table 1.4-1). The results of the KHNP sensitivity calculations are provide in Section 9 of Appendix A of the TR (KHNP 2018f).

2.2.4 NRC Staff's Review

The staff reviewed the KHNP MACCS model and input deck. Through the audit review and RAI process, the staff verified the appropriateness of the sources of data and models used by the applicant for calculating consequences from potential environmental releases of radioactive material. Confirmatory MACCS calculations were performed by the staff for KHNP's base case and selected sensitivity calculations. The staff arrived at similar results for the base case offsite consequences. For the sensitivity cases, the staff first reviewed the cases applied by KHNP and found them to be a reasonable set to examine for the APR1400 design. For the sensitivity results provided in Section 9 of Appendix A of the TR (KHNP 2018f), the staff examined the effect of the sensitivity case by comparing the sensitivity results to the base case (Case 1). For most sensitivity cases, the sensitivity case total is very similar to the base case (ratios ranging from of 0.9 to 1.1). Case 7 sensitivity results were less than the base case (i.e., a total result ratio of 0.8) and; therefore, the staff determined that the base case results are conservative and appropriate for use in the SAMDA cost-benefit analysis. However, Cases 10 and 10b results for offsite property damage costs are as much as 2.5 times greater than the base case. Therefore, the population dose and offsite property damage costs values for Case 10b should be applied in

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[4] [4] The term "averted" is defined for the purposes of this analysis as the avoidance of an impact, such as cost, due to the prevention or mitigation of an accident.

Section 6 of this report as a sensitivity calculation for assessing potentially cost-benefit SAMDAs. Finally, the staff would like to note that while KHNP also provided sensitivity results for individual early fatalities and latent cancer fatalities, these sensitivity results were not reviewed any further because they do not factor into the SAMDA cost-benefit analysis (i.e., not an input to the cost formulas and the analysis conducted in Section 6).

Based on its review of KHNP's submissions, the staff concludes that KHNP's methodology to estimate offsite consequences for APR1400 design provides an acceptable basis to assess the risk reduction potential for SAMDA candidates. Because the modeling assumptions included in the assessment and input data were either obtained for the Surry site, or found to be consistent with severe accident guidance, the staff concludes that the data and modeling assumptions for the offsite consequence analysis are appropriate for the SAMDA evaluation. Accordingly, the staff based its assessment of offsite risk on the core damage frequencies, population doses, and offsite economic costs reported by KHNP, which the staff also found to be acceptable.

3 Potential Plant Improvements

The process for identifying potential plant improvements, an evaluation of that process, and the improvements evaluated by KHNP are discussed in this section.

3.1 Process for Identifying Potential Plant Improvements

As discussed in Section 5 of the ER and the TR (KHNP 2018e and KHNP 2018f), KHNP identified potential plant improvements by the review of:

- NEI 05-01A Table 14 (NEI 2005); and
- Results from the APR1400 PRA (KHNP 2018d).

The standard list of PWR SAMAs[5] of NEI 05-01A Table 14 provides 153 SAMAs for an initial set of potential plant improvements. The 153 SAMAs are also listed in Table 5 of the ER and TR. Based on the guidance provided in Section 6 of NEI 05-01A (NEI 2005), KHNP reviewed this initial set to determine which SAMA could be screened for further consideration. The screening criteria applied by KHNP for removing SAMAs for further consideration were:

1. Not applicable to the APR1400 design or to the APR1400 DC;
2. Already implemented in the APR1400 design;
3. Excessive implementation costs; and
4. Very low benefit.

There were several considerations to the above screening criteria. Procedures and training are items that are not applicable to a DC application since these programs have yet to be developed. A SAMA would have excessive implementation costs if it would require extensive design changes that will exceed the maximum benefit even without an implementation cost estimate (see Table 10 of NEI 2005 for an example of this screening criteria). As for a SAMA with a very low benefit, this screening criteria applies if it is related to a non-risk-significant system or the change in reliability would have a negligible impact on the risk profile. Based on

[5] SAMA is applied in Section 3.1 since the standard list of pressurized water reactor SAMAs from NEI 05-01A does contain ones relating to procedures and training.

these screening criteria, and as shown in Table 5 of the ER and TR (KHNP 2018e and KHNP 2018f), KHNP screened out 115 of the NEI 05-01A SAMAs with 38 SAMDAs remaining.

Besides the initial set of SAMAs from NEI 05-01A, KHNP did include in the SAMDA search process inputs from an expert panel for additional APR1400 design-specific SAMDAs (KHNP 2014a). All of the potential SAMDAs considered by expert panel were either already implemented or not applicable to the DC application and removed from further consideration.

KHNP applied insights from the APR1400 PRA by way of two processes. First, as discussed in Section 5.1, PSA Importance, of NEI 05-01A (NEI 2005), KHNP indicated in the ER, TR, and DCD Chapter 19 how dominant failures were defined and the rationale for the cutoff value. This was accomplished by identifying APR1400-specific items from the PRA for further consideration for events with importance analysis to core damage cutsets based on a Fussell-Vesely (FV) importance of greater than 0.5 percent. The FV importance measures the overall percent contribution of those cutsets containing a basic event of interest to the total risk, namely total CDF (see Appendix A). By applying this criteria, KHNP identified a number of basic events as shown in ER and TR Tables 6a through 6f (KHNP 2018e and KHNP 2018f) based on the information in DCD Section 19.1 (KHNP 2018d). In summary, this process identified 126 basic events for at-power internal events, 110 for at-power internal flooding events, 120 for at-power internal fire events, 79 LPSD internal events, 75 LPSD internal flooding events, and 98 LPSD internal fire events.

The second process in applying insights from the APR1400 PRA involved reviewing the top 100 cutsets and identifying any basic events that were not included as part of the FV importance analysis review. This is also follows the guidance in NEI 05-01A Section 7 on the interpretation of dominant sequences. For this review, KHNP identified a number of basic events for further consideration as shown in ER and TR Tables 7a through 7f (KHNP 2018e and KHNP 2018f) based on the information in DCD Section 19.1 (KHNP 2018d).

3.2 NRC Staff Review of KHNP's Process

The staff reviewed the process applied by KHNP for the selection of the initial set of SAMDAs and for the additional basic events. The review included discussions as part of the environmental audit (NRC 2015c) and four RAIs. The RAIs asked for additional documentation and clarification regarding: (1) the bases as to why the costs for a SAMDA was excessive or the benefits negligible (Table 1.4-1 RAI 8429 EA ACC/SAMDA-1), (2) for additional justification for inclusion of the basic events (Table 1.4-1 RAI 8429 EA ACC/SAMDA-2), (3) for additional document on FV importance and 100 cutset basic event selection (Table 1.4-1 RAI 8429 EA ACC/SAMDA-4), and (4) additional information on the process the expert panel followed in their determination of potential SAMDAs (Table 1.4-1 RAI 8429 EA ACC/SAMDA-5). In the RAI responses, KHNP provided additional information and discussion with appropriate changes to the ER and TR being incorporated into revisions of both documents (KHNP 2018a, 2018b, 2018e, and 2018f). Since the FV importance and 100 cutsets are from the APR1400 PRA and documented in DCD Section 19.1, the staff's review of this material is discussed in FSER Chapter 19 (NRC 2018a). The staff found the APR400 PRA as documented in DCD Chapter 19 has adequately addressed the Commission's objectives regarding the prevention and mitigation of severe accidents.

Based on the above, the staff concludes that the set of SAMDAs and basic events evaluated in the ER and TR as supported by DCD Chapter 19, together with the responses to the staff RAIs, addresses the major contributor to core damage. The staff determined KHNP used a systematic and comprehensive process for identifying potential plant improvements for the APR1400 design, and that the set of potential plant improvements identified by KHNP is reasonably comprehensive and, therefore, acceptable for further evaluation. This search included reviewing insights from the plant-specific PRA study, as well as assessing SAMAs based on accepted industry guidance.

4 Risk Reduction Potential of Plant Improvements

The risk reduction potential of plant improvements as evaluated by KHNP are discussed in this section.

4.1 APR1400 Risk Reductions

KHNP evaluated the potential SAMDAs not screened-out to assess their potential benefits by using bounding techniques to estimate the possible risk reduction. This is accomplished by associating the basic events identified with a FV importance of greater than 0.5 percent, and from the top 100 cutsets to a particular SAMDA. This linkage to a SAMDA is provided for each basic event in Section 7.1 through to Section 7.19[6]. The basic event that a potential SAMDA is associated with is also provided in the "Qualitative Screening" column of ER and TR Table 5 (KHNP 2018e and KHNP 2018f).

Because there are likely several basic events that are considered under a specific SAMDA, KHNP applied a factor of risk reduction based on the sum of FV importance values. For example, the emergency diesel generator (EDG) events include the at-power internal events Item Numbers 14, 30, 56, 61, and 80 from Table 6a of the ER and TR (KHNP 2018e and KHNP 2018f) resulted in a combined risk reduction of approximately 16 percent. However, the basic events, which the standard PRA analysis practices model as independent events, do have dependencies with other basic events. Using the above EDG events as the example, Item Number 80, namely DG-A fails to start, is dependent on Item Number 14, DG-A unavailable due to test and maintenance. PRA experts recognize this dependency is not captured in the PRA models due to the added complexity without providing a noticeable benefit to the understanding of risk. The effect of not including dependencies is shown by the DCD Chapter 19, Table 19.1-24, FV values (KHNP 2018d), where the total FV value is greater than 200 percent rather than no greater than 100 percent. The staff views the treatment of risk reduction in this manner by ignoring dependencies as conservative in that the basic events would have a larger percentage of the total risk than by the PRA analyst taking potentially a significant amount of time and effort in accounting for dependencies.

KHNP determined that the sum of FV values for each basic event under the six risk categories (at-power internal events, internal flooding, and internal fire; LPSD internal events, internal flooding, and internal fire) for a total risk reduction percentage associated with a particular risk category. In several basic event cases, KHNP found there were no FV importance values so the sum for a risk category would be zero.

[6] SAMDA numbers are denoted as an "item" number at the beginning of Section 7.1 through Section 7.19. For example, at the beginning of Section 7.1, it is denoted emergency diesel generator events include items 9, 19, 20, and 29. These correspond to ER and TR Table 5 SAMDA ID numbers 9, 19, 20, and 29.

4.2 Staff Review of the Risk Reductions

The staff reviewed KHNP's bases for calculating the risk reduction for the various plant improvements and concludes that the rationale and assumptions for estimating risk reduction are reasonable. Specifically, the sum of FV importance values for risk reductions is acceptable due to its conservatism (i.e., the estimated risk reduction is higher than what would actually be realized). Accordingly, as will be presented in Section 6 of this technical review, the staff based its estimates of averted risk for the potential SAMDAs on the resulting APR1400 risk reduction estimates.

5 Cost Impacts of Candidate Plant Improvements

This section discusses the staff's review of the potential costs of the SAMDAs pertaining to APR1400 reactor design that were not screened out (see Section 3 of this report). In performing the cost benefit analysis of the SAMDAs considered, the cost of enhancement (COE) implementation associated with potential events are estimated based on available information related to similar events and components of other nuclear power plant designs. The COE cost values of the APR1400 SAMDAs are derived from two sources. The first source is the compilation of information from the SAMA analyses performed for the license renewal applications of the present operating nuclear power plants as documented the licensee's renewal ERs and in the final supplemental EIS (NRC 1996) under NUREG-1437 (e.g., NUREG-1437 FSEIS for the Callaway NPP is Supplement 51, or S51). Table 5.0-1 details the COE values extracted from these sources of information. The second source is an assessment by the applicant as presented in the ER and TR (KHNP 2018e and KHNP 2018f). The publicly available license renewal (LR) SAMA costs are full-cost values while the associated SAMDA cost applied by KHNP were conservatively set to half of the values from the LR analyses based on an assumption that half of the cost is from engineering and procedure updates. However, it is important to note for license renewal, the full SAMA costs were applied in their SAMA cost-benefit analyses. Therefore, the full-cost of a SAMA from license renewal should be applied in the same manner as part of the APR1400 SAMDA assessment.

As such, the staff performed the cost benefit analysis first using half of the SAMDA COE implementation value, as did KHNP in the APR1400 ER and TR. If SAMDAs were not further screened out based on the conservative assumptions, then the staff applied the full COE implementation value. This approach facilitates the performance of the cost benefit comparisons based on a graded approach when assessing the net present value (NPV) using the 7 percent then the 3 percent discount rates. As a result of this approach, this assessment demonstrates the point where economic viability of the proposed modification can be adequately gauged (i.e., an indication as to the cost margin a particular SAMDA has in order to be potentially cost-beneficial). The COE implementation values are next applied in the cost-benefit assessment for the NPV cost determinations as discussed in Section 6.

Table 5.0-1 Cost of Enhancement

APR1400 DC ER Section	Basic Events and associated components considered for Enhancement implementation	COE Source (Page No.)	COE Reference (ADAMS Accession No.)	COE Value ($k)	COE Half Value ($k)	AP1400 DC ER Section Applying COE
8.1	Emergency Diesel Generator Events	Palo Verde LR S43 (F-23)	FSEIS-ML103560149	$1,833	$900	9.01
8.2	AAC combustion Turbine Generator Events	Palo Verde LR S43 (F-23)	FSEIS-ML103560149	$1,833	$900	9.02
8.4	Fire Barrier Failure Events	Brunswick LR S25 (G-23)	FSEIS-ML060900480	$750	$350	9.04
8.7	125 VDC Power Events	Fitzpatrick LR S31 (G-25)	FSEIS-ML080170183	$500	$250	9.07
8.8	120 VAC Power Events	Fitzpatrick LR S31 (G-26)	FSEIS-ML080170183	$300	$300	9.08
8.9.2	POSRVs	Susquehanna LR S35 (G-20)	FSEIS-ML090700454	$660	$328	9.10
8.14	ECW Pumps	Callaway LR S51 (F-26)	FSEIS-ML14289A140	$500	$250	9.14
8.3.1	AFW Isolation Valve Events	Vermont Yankee LR S30 (G-36)	FSEIS-ML072050013	$712	$350	9.03.1
8.3.2	AFW Pumps	Millstone LR S22 (H-18)	FSEIS-ML051960299	$12,000	$6,000	9.03.2
8.3.2	Startup FW PP07 Events	Millstone LR S22 (H-18)	FSEIS-ML051960299	$12,000	$6,000	9.03.3
8.5.2	DG001A CCW Inlet Valve MOV-191	Brunswick LR S25 (G-24)	FSEIS-ML060900480	$100	$50	9.05.1
8.5.1	CCW Pumps	Callaway LR S51 (F-26)	FSEIS-ML14289A140	$1,000	$500	9.05.2
8.5.2	CS Heat Exchanger Isolation Valves	Brunswick LR S25 (G-24)	FSEIS-ML060900480	$100	$50	9.05.3
8.6.1	Containment Spray Pumps	Callaway LR S51 (F-28)	FSEIS-ML14289A140	$2,000	$1,000	9.06.1
8.6.2	Total Containment Spray Isolation Valve Event Summary	Brunswick LR S25 (G-24)	FSEIS-ML060900480	$100	$50	9.06.2
8.6.3	Containment Spray Heat Exchangers	Callaway LR S51 (F-28)	FSEIS-ML14289A140	$2,000	$1,000	9.06.3
8.9.1	SAT Transformers	KHNP	ML18066A595	$3,000	$3,000	9.09.1
8.9.2	4.16KV Circuit Breakers it should be 187500-330000=-142500	Susquehanna LR S35 (G-20)	FSEIS-ML090700454	$660	$328	9.09.2
8.11	ECW Chiller Summary	Vermont Yankee LR S30 (G-19)	FSEIS-ML072050013	$2,200	$1,100	9.11.1

Table 5.0-1 Cont'd

APR1400 DC ER Section	Basic Events and associated components considered for Enhancement implementation	COE Source (Page No.)	COE Reference (ADAMS Accession No.)	COE Value ($k)	COE Half Value ($k)	AP1400 DC ER Section Applying COE
8.11	EDG Room Cubical Coolers	Vermont Yankee LR S30 (G-19)	FSEIS-ML072050013	$2,200	$1,100	9.11.2
8.11	Motor Driven AFW Pump Room Cubical Coolers	Vermont Yankee LR S30 (G-19)	FSEIS-ML072050013	$2,200	$1,100	9.11.3
8.11	Air Handling Units	Vermont Yankee LR S30 (G-19)	FSEIS-ML072050013	$2,200	$1,100	9.11.4
8.12.1	SI Pumps PPO2D Events	Callaway LR S51 (F-24)	FSEIS-ML14289A140	$1,500	$750	9.12.1
8.12.2	IRWST Strainer Events	KHNP	ER-ML18066A595	$1,000	$1,000	9.12.2
8.12.3	SI Valve V-959 Events	Brunswick LR S25 (G-24)	FSEIS-ML060900480	$100	$50	9.12.3
8.13.1	ESW Filer Plugging Events	Brunswick LR S25 (G-24)	FSEIS-ML060900480	$100	$100	9.13.1
8.13.4	ESW HOV-074 it should be 8400-50000= -41600	Brunswick LR S25 (G-24)	FSEIS-ML060900480	$100	$50	9.13.2
8.13.2	ESW Pumps	Callaway LR S51 (F-25)	FSEIS-ML14289A140	$5,000	$2,500	9.13.3
8.13.3	Total ESW Cooling Tower Events Summary	KHNP	ER-ML18066A595	$100	$100	9.13.4
8.16	PPS Loop Controller Application Software	KHNP	ER-ML18066A595	$1,000	$1,000	9.16.1
8.16	PPS Group Controller Application Software	KHNP	ER-ML18066A595	$1,000	$1,000	9.16.2
8.16	PPS Loop Controller Operating System Software	KHNP	ER-ML18066A595	$1,000	$1,000	9.16.3
8.17.1	Main Steam Atmospheric Dump Valve(V-102	Callaway LR S51 (F-27)	FSEIS-ML14289A140	$500	$250	9.17.1
8.17.2	Main Steam Isolation Valves	KHNP	ER-ML18066A595	$200	$200	9.17.2
8.17.3	Main Steam Safety Valves	Callaway LR S51 (F-27)	FSEIS-ML14289A140	$500	$250	9.17.3
8.18	TGBCCW Pump Train 2 Events	KHNP	ER-ML18066A595	$250	$250	9.18.1
8.19	SDC Pumps	Callaway LR S51 (F-28)	FSEIS-ML14289A140	$2,000	$1,000	9.19.1

Sources - FSEISs: NRC 1996; ER; KHNP 2018a

6 Cost Benefit Comparison

KHNP's cost-benefit analysis and the staff's review are described in the following sections.

6.1 Introduction

The methodology used by KHNP was based primarily on NRC's guidance for performing cost-benefit analysis, NUREG/BR-0184 (NRC 1997) and industry guidance (NEI 2005) endorsed by NRC for LR. However, as previously discussed in this report, the methodology presented in the industry guidance has use in new reactor licensing SAMDA assessments. As described in Section 4 of the ER and the TR (KHNP 2018e and KHNP 2018f), the unmitigated risk monetary value, or the NPV of current risk, is calculated using the following formula:

NPV = (APE + AOC + AOE + AOSC) – COE

Where:

NPV = Net present value of current risk ($);
APE = Present value of averted public exposure[7] ($);
AOC = Present value of averted offsite property damage costs ($);
AOE = Present value of averted occupational exposure ($);
AOSC = Present value of averted onsite costs ($); and
COE = Cost of any enhancement implemented to reduce risk ($).

For the representation of the maximum benefit that could be provided, the maximum benefit is calculated to be the sum of the four averted cost categories. It is represented as:

Maximum Benefit = APE + AOC + AOE + AOSC

KHNP's derivation of each of the associated costs along with the staff's assessment are presented in Section 6.2. The application of COE implementation costs in comparison to the Maximum Benefit for determining the NPV for each mitigation item is presented in Section 6.3.

In accordance with NUREG/BR-0058 guidance (NRC 2004), present worth estimates should be developed using both the 7 percent and 3 percent discount rates, which is also discussed in Section 8.5 of NEI 05-01A (NEI 2005). Therefore, KHNP conducted a baseline analysis using the 7 percent discount rate and a sensitivity analysis using the 3 percent discount rate. The details of the applicant's base line analysis is found in Section 4 of the ER and TR with the sensitivity analysis details provided in Section 10 of the ER and TR (KHNP 2018e and KHNP 2018f). KHNP's results are shown below in Section 6.2 for each averted cost category. The results from staff's review of the KHNP's base line and sensitivity analysis are also provided next to the KHNP results for each averted cost category.

6.2 Maximum Benefit Assessment

6.2.1 Averted Public Exposure (APE)

KHNP defines APE costs as the present value of averted public exposure. The APE costs were calculated using the following formula:

$APE = (F_S D_{PS} – F_A D_{PA}) * R * (1 – e^{\wedge} (-r*t_f)) / r$

Where:

APE = Present value of averted public exposure ($);
R = Monetary equivalent of unit dose ($2,000/person-rem);
F_S = Baseline accident frequency (events per year);
F_A = Accident frequency after mitigation (0 events per year);
$F_S D_{PS}$ = Baseline accident offsite dose frequency (person-rem per year);
$F_A D_{PA}$ = Accident offsite dose frequency after mitigation (0 person-rem per year);
r = Real discount rate (7% or 3% per year); and
t_f = Years remaining until end of plant life (60 years).

Using the equation and parameters as defined above, KHNP calculated the APE for at-power internal events, internal flooding events, and internal fire events; along with LPSD internal events, internal flooding events, and internal fire events. The results of the KHNP and staff evaluations are provided in Table 6.2-1.

Table 6.2-1 Calculated APE Comparison

Risk Category	KHNP		NRC Staff	
	7%	3%	7%	3%
At-Power Internal Events	$15,000	$29,659	$15,000	$29,660
At-Power Internal Flooding Events	$1,551	$3,066	$1,551	$3,066
At-Power Internal Fire Events	$16,294	$32,219	$16,295	$32,219
LPSD Internal Events	$9,399	$18,586	$9,400	$18,586
LPSD Flooding Events	$3,946	$7,802	$3,940	$7,791
LPSD Fire Events	$3,687	$7,290	$3,687	$7,290
Total APE	$49,877	$98,622	$49,872	$98,612

6.2.2 Averted Offsite Property Damage Costs (AOC)

KHNP defines AOC as the present value of averted offsite property damage costs. The AOC were calculated using the following formula:

$AOC = (F_S P_{DS} – F_A P_{DA}) * (1 – e^{\wedge} (-r*t_f)) / r$

Where:

AOC = Present value of averted offsite property damage costs ($);
$F_S P_{DS}$ = Baseline accident frequency * property damage (cost per year from Tables 4a through 4f);
$F_A P_{DA}$ = Accident frequency * property damage after mitigation (0 events per year);
r = Real discount rate (7% or 3% per year); and
t_f = Years remaining until end of plant life (60 years).

Using the equation and parameters as defined above, KHNP calculated the AOC for at-power internal events, internal flooding events, and internal fire events, along with LPSD internal events, internal flooding events, and internal fire events. The results of the KHNP and staff evaluations are provided in Table 6.2-2.

Table 6.2-2 Calculated AOC Comparison

Risk Category	KHNP		NRC Staff	
	7%	3%	7%	3%
At-Power Internal Events	$21,580	$42,671	$21,586	$42,681
At-Power Internal Flooding Events	$1,992	$3,938	$1,998	$3,951
At-Power Internal Fire Events	$19,070	$37,707	$19,067	$37,701
LPSD Internal Events	$12,422	$24,563	$12,425	$24,568
LPSD Flooding Events	$4,423	$8,746	$4,418	$8,737
LPSD Fire Events	$4,446	$8,792	$4,447	$8,792
Total AOC	$63,933	$126,417	$63,941	$126,429

6.2.3 Averted Occupational Exposure (AOE)

KHNP defines AOE as the present value of averted occupational exposure. The AOE were calculated using the following formulas:

$AOE = W_{IO} + W_{LTO}$
$W_{IO} = (F_S D_{IOS} – F_A D_{IOA}) * R * (1 – e^{\wedge} (-r*t_f)) / r$
$W_{LTO} = (F_S D_{LTOS} – F_A D_{LTOA}) * R * [(1 – e^{\wedge} (-r*t_f)) / r] * [(1 – e^{\wedge} (-r*m) / (r*m)]$

Where:

AOE = Present value of averted occupational exposure ($);
W_{IO} = Present value of averted immediate occupational exposure ($);
F_S = Baseline accident frequency (events per year from Tables 1a and 1b);
F_A = Accident frequency after mitigation (0 events per year);
D_{IOS} = Baseline expected immediate onsite dose (3,300 person-rem/event);
D_{IOA} = Expected occupational exposure after mitigation (3,300 person-rem/event);
R = Monetary equivalent of unit dose ($2,000/person-rem);
r = Real discount rate (7% or 3% per year);

t_f = Years remaining until end of plant life (60 years);
W_{LTO} = Present value of averted long-term occupational exposure ($);
D_{LTOS} = Baseline expected long-term onsite dose (20,000 person-rem/event);
D_{LTOA} = Expected occupational exposure after mitigation (20,000 person-rem/event); and
m = Years over which long-term doses accrue (10 years from KHNP 2018b).

Using the equation and parameters as defined above, KHNP calculated the AOE for at-power internal events, internal flooding events, and internal fire events; along with LPSD internal events, internal flooding events, and internal fire events. The results of the KHNP and staff evaluations are provided in Table 6.2-3.

Table 6.2-3 Calculated AOE Comparison

Risk Category	KHNP		NRC Staff	
	7%	3%	7%	3%
At-Power Internal Events	$498	$1,146	$498	$1,145
At-Power Internal Flooding Events	$190	$437	$190	$437
At-Power Internal Fire Events	$1,388	$3,195	$1,388	$3,195
LPSD Internal Events	$965	$2,221	$965	$2,222
LPSD Flooding Events	$40	$93	$40	$92
LPSD Fire Events	$736	$1,695	$737	$1,695
Total AOE	$3,817	$8,787	$3,818	$8,786

6.2.4 Averted Onsite Cost (AOSC)

KHNP defines AOSC as the costs associated with onsite property damage from an accident: cleanup and decontamination, long-term replacement power, and repair and refurbishment. The total averted onsite property damage costs are the sum of these three types of costs. The AOSC were calculated using the following formula:

$AOSC = U_{CD} + U_{RP} + 0$

The discussions for U_{CD} and U_{RP} are provided below.

6.2.4.1 Averted Cleanup and Decontamination Costs (U_{CD})

The estimated clean-up cost for severe accidents is defined in NUREG/BR-0814, Section 5.7.6.1, to be $\$1.5\times10^9$ per accident, undiscounted (i.e., not adjusted for inflation). The present value of the payments needed for cleanup and decontamination costs is calculated using the following formula:

$PV_{CD} = (C_{CD} / m) * ((1 – e^\wedge (-r*m)) / r$

Where:

PV_{CD} = Present value of averted onsite cleanup costs exposure over cleanup period ($);
C_{CD} = Total value of averted onsite cleanup costs ($\$1.5 \times 10^9$/event);
r = Real discount rate (7% or 3% per year);
m = Years over which long-term doses accrue (10 years);
$PV_{CD} = ((\$1.5\times10^9/\text{event}) / (10 \text{ years})) * ((1 - e^{-(0.07*10)}) / 0.07)$; and
$PV_{CD} = \$1.08\times10^9$.

The net present value of averted cleanup costs over the plant life is calculated using the following formula:

$U_{CD} = (F_S - F_A) * PV_{CD} * (1 - e\text{^} (-r*t_f)) / r$

Where:

U_{CD} = Present value of averted onsite cleanup costs ($);
F_S = Baseline accident frequency (events per year from Tables 1a and 1b);
F_A = Accident frequency after mitigation (0 events per year);
PV_{CD} = Present value of averted onsite cleanup costs exposure over cleanup period ($); and
t_f = Years remaining until end of plant life (60 years).

Using the equation and parameters as defined above, KHNP calculated the U_{CD} for at-power internal events, internal flooding events, and internal fire events; along with LPSD internal events, internal flooding events, and internal fire events. The results of the KHNP and staff evaluations are provided in Table 6.2-4.

Table 6.2-4 Calculated U_{CD} Comparison

Risk Category	KHNP		NRC Staff	
	7%	3%	7%	3%
At-Power Internal Events	$15,178	$36,056	$24,898	$59,142
At-Power Internal Flooding Events	$5,798	$13,773	$9,511	$22,592
At-Power Internal Fire Events	$42,348	$100,596	$69,466	$165,006
LPSD Internal Events	$29,446	$69,948	$48,303	$114,735
LPSD Flooding Events	$1,223	$2,906	$2,007	$4,767
LPSD Fire Events	$22,464	$53,363	$36,850	$87,530
Total U_{CD}	$116,457	$276,642	$191,035	$453,773

6.2.4.2 Averted Replacement Power Cost (U_{RP})

The averted replacement power costs is defined as the net present value of replacement power over life of facility and is calculated by the following formulas:

PV_{RP} = [($1.2E+8 * (Rated Power) / (910 MWe)) / r] * (1 – e^ (-r*t_f))^2
U_{RP} = (F_S – F_A) * PV_{RP} / r * (1 – e^ (-r*t_f))^2

Where:

U_{RP} = Net present value of replacement power over life of facility (dollars);
FS = Baseline accident frequency (events per year from Tables 1a and 1b);
FA = Accident frequency after mitigation (0 events per year);
PVRP = Net present value of replacement power for a single event ($);
r = Real discount rate (7% per year);
tf = Years remaining until end of plant life (60 years); and
Rated power = 1400 MWe.

For the 3 percent discount rate, KHNP applied the guidance provided on page 5.45 of Section 5.7.6.2, Long-term Replacement Power, of NUREG/BR-0184 using a linear interpolation for the value of U_{RP} (KHNP 2018b).

Using the equations and parameters as defined above and adjusted for inflation when appropriate, KHNP calculated the UCD for at-power internal events, internal flooding events, and internal fire events, along with LPSD internal events, internal flooding events, and internal fire events. The results of the KHNP and staff evaluations are provided in Table 6.2-5.

Table 6.2-5 Calculated U_{RP} Comparison

Risk Category	KHNP		NRC Staff	
	7%	3%	7%	3%
At-Power Internal Events	$87,986	$147,883	$92,110	$244,992
At-Power Internal Flooding Events	$33,611	$56,490	$35,186	$93,587
At-Power Internal Fire Events	$245,482	$412,590	$256,988	$683,528
LPSD Internal Events	$170,693	$286,890	$178,694	$475,285
LPSD Flooding Events	$7,092	$11,920	$7,424	$19,746
LPSD Fire Events	$130,220	$218,865	$136,323	$362,588
Total U_{RP}	$675,084	$1,134,638	$706,726	$1,879,727

6.2.4.3 Averted Repair and Refurbishment Costs

KHNP has stated that they assume the plant would not be repaired or refurbished, and therefore assume a cost of zero for the repair and refurbishment costs.

6.2.4.4 Total AOSC

As discussed at the start section 6.2.4, the equation for the AOSC is represented as:

$AOSC = U_{CD} + U_{RP} + 0$

The results of the KHNP and staff evaluations are provided in Table 6.2-6.

Table 6.2-6 Calculated AOSC Comparison

Risk Category	KHNP		NRC Staff	
	7%	3%	7%	3%
At-Power Internal Events	$103,164	$183,939	$117,009	$377,620
At-Power Internal Flooding Events	$39,409	$70,263	$44,697	$123,634
At-Power Internal Fire Events	$287,830	$513,186	$326,454	$921,649
LPSD Internal Events	$200,139	$356,838	$226,997	$635,396
LPSD Flooding Events	$8,315	$14,826	$9,431	$41,133
LPSD Fire Events	$152,684	$272,228	$173,173	$467,895
Total AOSC	$791,541	$1,411,280	$897,761	$2,567,327

6.2.5 Total Maximum Benefit

Using the above equations, KHNP estimated the total unmitigated baseline risk to be $909,168 for the 7 percent discount rate and $1,645,106 for the 3 percent discount rate. These values utilize the equation Maximum Benefit = (APE + AOC + AOE + AOSC). The resulting Maximum Benefit represents the maximum risk benefit attainable if all core damage scenarios are eliminated over the 60-year plant life. Table 6.2-7 is a summary of the total results generated for the Total Maximum Benefit. The staff also notes the use of $AOSC_{CD}$ and $AOSC_{RP}$ in place of the U_{CD} and U_{RP} values, respectively, when summarizing the results in Table 6.2-7.

Table 6.2-7 Calculated Total Maximum Benefit

Risk Category	KHNP		NRC Staff	
	7%	3%	7%	3%
APE	$49,877	$98,622	$49,872	$98,612
AOC	$63,933	$126,417	$63,941	$126,429
AOE	$3,817	$8,787	$3,818	$8,786
$AOSC_{CD}$	$116,457	$276,642	$191,035	$453,773
$AOSC_{RP}$	$675,084	$1,134,638	$706,726	$1,879,727
Total Maximum Benefit	$909,168	$1,645,106	$1,015,393	$2,567,327

6.3 Net Present Value Evaluation

6.3.1 KHNP's Results

If the implementation costs for a SAMDA candidate exceeded the calculated maximum benefit, resulting in a negative NPV, the SAMDA would be determined to be not cost-beneficial. If the SAMDA benefit exceeded the estimated cost resulting in a positive NPV, the SAMDA candidate would be considered to be potentially cost-beneficial. KHNP's cost-benefit analysis initially identified 153 SAMDA candidates to be considered in the cost-beneficial analysis. As discussed in Section 3 of this report, a number of potential SAMDAs were screened out and only 38 SAMDAs were carried to the next screening phase. In addition to these remaining SAMDAs, each basic event with a FV importance of greater than 0.5 percent or part of the top 100 cutsets, if not already included as a basic event, were reviewed to identify any potential SAMDAs. As presented in the disposition column of Table 5 in the ER and TR, KHNP then related each of the 38 SAMDAs back to one or more of the basic events by performing for the 7 percent discount rate analysis with the following steps (KHNP 2018a and KHNP 2018b):

1. Provided in Section 7.1 of the ER and TR the maximum benefit for each basic event applying conservative assumptions for risk reductions to the AOE and AOSC cost categories;
2. Assessed a cost of enhancement in Section 8 of the ER and TR based on half of the SAMDA values obtained from license renewal documents'; and
3. Presented in Section 9 of the ER and TR the NPV results.

KHNP states in Section 11 of the ER and TR that a second maximum benefit analysis was calculated for the 3 percent discount rate. However, KHNP did not provide detailed results for the 3 percent discount rate in a similar manner as provided in Sections 7, 8, and 9 of the ER and TR (KHNP 2018e and KHNP 2018f). The staff is assuming KHNP applied similar steps for the 3 percent discount rate as performed for the 7 percent discount rate. From this, the staff produced the 3 percent discount rate results of the KHNP cost-benefit evaluation as presented in Table 6.3-1.

For each of the basic events/SAMDAs described above, KHNP evaluated the NPV and reached a conclusion if the enhancements were cost beneficial. KHNP's SAMDA analysis determined that there were no potentially cost-beneficial enhancements for the 7 percent discount rate analysis as shown by the negative NPV values in Table 6.3-1. KHNP's states in Section 11 of the ER and TR that their sensitivity analysis for the 3 percent discount rate showed a higher maximum benefit over the 7 percent discount rate (KHNP 2018a and KHNP 2018b). KHNP concluded that no design changes would provide a positive cost-benefit for either discount rate if included in the APR1400 design. However, as shown in Table 6.3-1, there are six basic events where the NPV is positive under KHNP's conservative assumptions. Therefore, the staff will re-assess this conclusion of the applicant's in the next section as part of the staff's review.

6.3.2 NRC Staff's Results

During its review of the cost-benefit analysis performed by KHNP, the staff compared the applicant's approach with the guidance in NUREG/BR-0184 (NRC 1997) and discount rate guidelines in NUREG/BR-0058 (NRC 2004) and incorporated into NEI 05-01 (NEI 2005). The guidance states that two sets of estimates should be developed, namely for discount rates of 7 percent and 3 percent (NEI 2005). KHNP performed assessments using both discount rates. KHNP provided a baseline set of results using a discount rate of 7 percent. By applying information from Section 5 and the formulas listed in Section 6.2 of this report, the staff's confirmatory analysis for the 7 percent discount rate were in general agreement with that part of the applicant's analysis. The staff's confirmatory analysis showed that there were no cost beneficial enhancements using a 7 percent discount rate. Based on the staff's review of the methodology and associated analysis, KHNP's information provided in the ER and TR with RAI responses and subsequent information adequately addressed the cost-benefit analysis for the 7 percent discount rate.

The staff review noted that the applicant used two assumed conservatisms in their analysis. The first case of conservatism used involved the total averted costs in each analysis where the applicant did not apply the percent risk reductions for the contribution to total CDF to the population dose (APE) and offsite property damage (AOC) costs. The value of APE and AOC were based on MACCS calculations and, thus, directly tied to the size of a release. As shown by the staff's 3 percent discount rate analysis to the KHNP's 3 percent discount rate analysis, by applying this reduction to only the onsite exposure (AOE) and onsite economic costs (AOSC) results in a conservative result. Namely, that it will result in a total maximum benefit larger than if the percentage risk reduction is applied to all cost categories. Thus, there would be a greater chance to provide a positive cost-benefit result. The second conservative assumption involved the use of the determined COE values, as discussed in Section 5. As assessed by the staff, when the applicant applies only half of the estimated COE value, the final determination of the cost-benefit analysis for some cases would more likely provide a positive NPV, indicating the potential for a cost-beneficial SAMDA.

Using KHNP's information presented in the ER and TR as previously discussed in this report, the staff performed a confirmatory calculation to verify the reported cost-benefits for the 3 percent discount rate. In performing the analysis using a 3 percent discount rate, the staff identified several scenarios which would be considered cost beneficial while considering the conservatisms assumed by the applicant. In the staff's sensitivity analysis, the staff removed the conservatism in applying the risk reduction percentages also to the APE and AOC values since they are also dependent on the released plume, and applied a full COE value for each of the SAMDAs. As a result, all of the items in the 3 percent discount rate analysis now have a negative NPV and were not cost beneficial. These results of are provided in Table 6.3-1.

The staff also conducted a sensitivity analysis based on the population dose risk and offsite property damage risk values that were obtained in the offsite consequence sensitivity Case 10b (see Section 2.2.4 of this report) for both the 7 percent and 3 percent discount rates. The staff finds the difference between Case 10 and Case 10b sensitivity runs is not significant and still maintains the negative NPV values (i.e., not cost beneficial) with the relaxed KHNP's conservatisms.

Table 6.3-1 Comparison of the NPV values per scenario by cost reduction

Section No.	Event Scenario	SAMDA No.	KHNP NPV		NRC Staff NPV	
			7%	3%	7%	3%
7.5.7	CS Heat Exchanger Isolation Valves	59	-$9,500	***+$26,624***	-$96,849	-$92,078
7.13.3	ESW Filer Plugging Events	43, 46, & 47	-$10,200	***+$75,673***	-$87,536	-$68,709
7.12.7	SI Valve V-959 Events	26, 29, 37, 38, & 39	-$11,300	***+$25,916***	-$95,787	-$89,309
7.6.8	Total Containment Spray Isolation Valve Event Summary	Not Listed	-$11,700	***+$25,439***	-$97,645	-$94,119
7.13.10	Total ESW Cooling Tower Events Summary	66, 67, 71, 75, 77, & 78	-$26,000	***+$45,474***	-$94,036	-$84,721
7.5.5	DG001A CCW Inlet Valve MOV-191	59	-$41,500	-$33,273	-$99,786	-$99,506
7.9.11	4.16KV Circuit Breakers	16	-$140,500	***+$28,180***	-$562,238	-$408,681
7.3.8	AFW Isolation Valve Events	66, 67, 71, 75, 77, & 78	-$141,100	-$51,852	-$609,408	-$450,475
7.7.5	125 VDC Power Events	1, 2, 3, 5, & 74	-$148,800	-$54,717	-$467,798	-$418,192
7.14.3	ECW Pumps	Not Listed	-$155,700	-$65,091	-$486,901	-$466,573
7.17.2	Main Steam Isolation Valves	89	-$159,100	-$119,970	-$193,590	-$184,291
7.10.5	POSRVs	Not Listed	-$181,900	-$194,766	-$651,287	-$637,589
7.13.8	ESW HOV-074	43, 46, & 47	-$191,600	-$33,377	-$99,911	-$99,794
7.8.5	120 VAC Power Events	6, 7, & 16	-$193,100	-$128,482	-$284,350	-$260,285
7.17.1	Main Steam Atmospheric Dump Valve (V-102)	89	-$201,500	-$159,728	-$498,686	-$496,670
7.17.3	Main Steam Safety Valves	89	-$209,400	-$169,801	-$499,296	-$498,266
7.18	TGBCCW Pump Train 2 Events	Not Listed	-$212,700	-$176,666	-$247,603	-$243,917
7.4.1	Fire Barrier Failure Events	143	-$292,000	-$238,044	-$732,011	-$704,204
7.5.6	CCW Pumps	59	-$412,500	-$327,688	-$995,477	-$988,493
7.12.5	SI Pumps PPO2D Events	26, 29, 37, 38, & 39	-$412,900	-$549,275	-$1,489,437	-$1,473,077
7.1.5 & 7.1.6	Emergency Diesel Generator Events	9, 19, 20, & 29	-$605,000	-$356,213	-$1,516,774	-$1,082,167

Table 6.3-1 Cont'd

Section No.	Event Scenario	SAMDA No.	KHNP NPV		NRC Staff NPV	
			7%	3%	7%	3%
7.2	AAC combustion Turbine Generator Events	15	-$774,400	-$692,029	-$1,812,595	-$1,784,869
7.16.1	PPS Loop Controller Application Software	Not Listed	-$824,700	-$757,665	-$964,367	-$909,870
7.11.16	ECW Chiller Summary	80, 81, & 82	-$898,400	-$719,807	-$2,085,666	-$1,906,449
7.12.6	IRWST Strainer Events	26, 29, 37, 38, & 39	-$927,200	-$858,805	-$981,259	-$952,810
7.19.3	SDC Pumps	Not Listed	-$928,400	-$859,579	-$1,994,318	-$1,985,456
7.6.7	Containment Spray Pumps	Not Listed	-$931,100	-$865,163	-$1,991,372	-$1,978,071
7.16.3	PPS Loop Controller Operating System Software	Not Listed	-$940,500	-$882,871	-$997,160	-$992,787
7.6.9	Containment Spray Heat Exchangers	Not Listed	-$960,700	-$923,506	-$1,996,943	-$1,992,314
7.16.2	PPS Group Controller Application Software	Not Listed	-$962,500	-$925,949	-$998,567	-$996,488
7.11.18	Motor Driven AFW Pump Room Cubical Coolers	80, 81, & 82	-$985,500	-$877,159	-$2,178,939	-$2,146,364
7.11.17	EDG Room Cubical Coolers	80, 81, & 82	-$989,300	-$878,102	-$2,186,555	-$2,165,555
7.11.19	Air Handling Units	80, 81, & 82	-$1,064,900	-$1,030,831	-$2,198,249	-$2,195,565
7.13.9	ESW Pumps	43, 46, & 47	-$2,378,500	-$2,262,786	-$4,980,611	-$4,950,526
7.9.10	SAT Transformers	16	-$2,945,000	-$2,894,379	-$2,980,484	-$2,950,106
7.3.9 & 7.3.10	AFW Pumps	66, 67, 71, 75, 77, & 78	-$5,833,200	-$5,689,174	-$11,885,024	-$11,708,992
7.3.7	Startup FW PP07 Events	66, 67, 71, 75, 77, & 78	-$5,962,800	-$5,925,338	-$11,998,058	-$11,995,242

6.4 Items Not Confirmed Under the NRC Review

During the review of the analysis performed by KHNP, the staff was not able to reproduce several of the values provided in Section 7 of the ER and TR. Most of the discrepancies found involved the at-power flooding events where the applicant's AOE+AOSC values were 4.22 times higher than the staff's value. However, the staff determined that contributions from the at-power flooding events were a fraction of the total maximum benefit (e.g., 5 percent or less) and did not affect the final results.

7 Conclusions

The staff reviewed KHNP's SAMDA analysis and concludes that the methods used and the implementation of the methods are appropriate. On the basis of the applicant's treatment of SAMDA benefits and costs, the staff finds that the SAMDA evaluations performed by KHNP are reasonable and sufficient. Based on its own independent evaluation, the staff reached the similar conclusion as KHNP that none of the SAMDA candidates are potentially cost beneficial for APR1400. This independent evaluation was based on reasonable treatment of costs, benefits, and sensitivities. Based on the staff's review of KHNP's SAMA evaluations, including KHNP's response to the staff's RAIs, the staff concludes that KHNP has adequately identified areas where risk potentially could be reduced in a cost-beneficial manner and adequately assessed whether the implementation of the identified potential SAMDAs would be cost-beneficial for the given site parameters.

Because of the magnitude of the negative NPV values, a SAMA based on operational procedures or training for an APR1400 reactor would have to significantly reduce the risk with a smaller CDF and/or the procedure or training SAMA would have a low implementation cost to become cost beneficial. Based on its evaluation, the staff concludes that it is unlikely that any of the SAMAs based on procedures or training would reduce the risk to be cost beneficial for the given site parameters.

8 References

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APPENDIX A: Definition of the Fussell-Vesely Importance

The Fussell-Vesely (FV) importance measures the overall percent contribution of cut sets containing a basic event of interest to the total risk

FV importance is calculated by finding the value of cut sets that contain the basic event of interest (xi) and dividing by the value of all cut sets representing the total risk (baseline risk). Namely:

$$FV_{xi} = F(i) / F(x)$$

Where,

F(i) is risk from just those cut sets that contain event xi; and
F(x) is the total risk from all cut sets.

FV Importance Measure Calculation Example

- Consider these minimal cut sets:

  $T * A = 1/\text{year} * 6 \times 10^{-4} = 6 \times 10^{-4}$ /year
  $T * B * C = 1/\text{year} * 1 \times 10^{-2} * 3 \times 10\text{-}3 = 3 \times 10^{-5}$ /year
  $T * C * D = 1/\text{year} * 3 \times 10^{-3} * 1 \times 10\text{-}3 = 3 \times 10^{-6}$ /year
  $F(x) = 6 \times 10^{-4} + 3 \times 10^{-5} + 3 \times 10^{-6} = 6.33 \times 10^{-4}$ /year

  Where:

  T = 1/year
  $A = 6 \times 10^{-4}$
  $B = 1 \times 10^{-2}$
  $C = 3 \times 10^{-3}$
  $D = 1 \times 10^{-3}$

- Resulting FV importance values:

  $FV_T = 6.33 \times 10^{-4}$ /yr ÷ 6.33×10^{-4} /yr = 1.0
  $FV_A = 6.00 \times 10^{-4}$ /yr ÷ 6.33×10^{-4} /yr = 0.948
  $FV_B = 3.00 \times 10^{-5}$ /yr ÷ 6.33×10^{-4} /yr = 0.047
  $FV_C = 3 \times 10^{-5}$ /yr + 3×10^{-6} /yr ÷ 6.33×10^{-4} /yr = 0.052
  $FV_D = 3.00 \times 10^{-6}$ /yr ÷ 6.33×10^{-4} /yr = 0.005

Source: Slide Presentation for Module N, “Importance Measures,” Document Title: 0505 - P111 - PRA Technology and Regulatory Perspectives - V1 - 14 - Importance Measures. Idaho National Laboratory. June 8, 2012. ADAMS Accession Number ML12160A479.

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